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DGs Placement in Reconfigured Electric Network for Loss Reduction and Voltage Enhancement using. Artificial Intelligence Algorithm

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Abstract: Nuclear facilities are more sensitive to any disturbance in electric power, so the power feeding these loads must be more reliable and of a higher quality. The capacity of feeding feeders to nuclear loads must be high to carry all facility loads. The major problems in distribution systems are how to improve the voltage profile and reduce power loss. These problems can be solved by the optimal placement of distributed generation units (**DGs**) in a reconfigured distribution network. In this study, the optimal location and size of DGs in a distribution network with network reconfiguration will be analyzed to get a distribution system with higher power quality and a reliable network design. In this paper, a mathematical model for the problem and an optimization technique based on the Modified Artificial Bee Colony algorithm (MABC) are proposed to reduce the electric network power losses and improve the network voltage profile. The proposed methodology is applied to IEEE-33, IEEE-69 standard distribution networks to check the accuracy and reliability. The obtained results are confirmed to be compatible with those found using other algorithms, where results and analysis showed the effectiveness and accuracy of the presented algorithm.

Keywords: distributed generation/ network reconfiguration/loss reduction/artificial bee colony.

1. Introduction

The radial distribution feeders are the ideal arrangement for a distribution network to feed electric loads. All feeders in the distribution network are separated and connected using tie and sectionalizing network switches according to the state of the loads. The main target of the reconfiguration of the network is to minimize power losses and maintain voltage within specified constraints with no harmonics. Since there are different forms of network arrangement states according to the switches' position and load state, obtaining the optimum position is a complex problem. Utilities have focused on the techniques for loss minimization that optimally maximize distribution network performance and sustain the operational system at maximum efficiency. The techniques involve network reconfiguration, capacitor placement, and distributed generation (DG). The most promising approach to solving this issue is integration with DG.

Many research works have been done in the field of distribution network reconfiguration for losses reduction and voltage enhancement [1-8]. Other researchers are improving the distribution network voltage and minimizing power losses by DGs placement using different algorithms [9-16]. However, for a reliable distribution network with stable and improved voltage, the DGs will be installed in a reconfigured network optimally. To solve the problem of distribution network reconfiguration and the optimal location and size of distributed generators simultaneously in radial distribution systems, a hybrid Cuckoo search and Grey wolf (CS-GWO) optimization algorithm was proposed in [17]. In [18] wild geese algorithm (WGA) was proposed to maximize power loss reduction while considering the optimization of voltage profiles, DGs capacity limits by simultaneous implementation for network reconfiguration and DGs placement. Decimal-coded quantum particle swarm optimization (DQPSO) methodology proposed for solving feeder reconfiguration with different DGs sources models [19]. For optimal DGs placement and radial distribution network reconfiguration (RDN), a water-cycle algorithm (WCA) was proposed [20]. The Chaos Disturbed Beetle Antennae Search (CDBAS) algorithm was proposed for solving the multi-objective

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optimal DGs allocation in a reconfigured network [21].
For optimally placing DGs while considering network reconfiguration, Grey Wolf Optimizer (GWO) and Particle Swarm Optimizer (PSO) were proposed in [22]. Adaptive Shuffled Frogs Leaping Algorithm (ASFLA) was proposed to solve grid reconfiguration and DGs allocation [23]. In [24] Gravitational Search Algorithm (EGSA) was proposed to decrease losses and improve the transient stability index using multiple DG micro-turbines in a reconfigured distribution system. DGs' renewable sources placement in the reconfigured network for different scenarios is simulated and solved by the Moth-flame optimization (MFO) algorithm [25]. Genetic Algorithm (GA) was used to solve the power loss minimization objective function problem considering DGs placement in a reconfigured network by [26], and Harmony Search Algorithm (HSA) in [27]. For the same problem, a Refine Genetic Algorithm (RGA) was proposed for solving by [28]. Reconfiguration of the distribution network with DGs placement problem is mathematically modeled, and using Fireworks Algorithm (FWA) for solving the problem proposed in [29]. In [30] Modified Plant Growth Simulation Algorithm (MPGSA) was proposed for losses reduction and voltage improvement by reconfiguration of the distribution system with DGs. Uniform Voltage Distribution Algorithm UVDA for optimal DGs sitting in a reconfigured network was proposed in [31]. In [32] Stochastic Fractal Search algorithm (SFSA) was proposed for minimizing power losses by optimal sizing and siting of DGs with the distribution system. Reconfiguration of the distribution system for power loss reduction and voltage improvement with DGs placement using the cuckoo Search Algorithm (CSA) proposed by [33]

In this paper, power losses minimization with network voltage and current maintaining within a certain limit by DGs integration in a reconfigured network will be investigated. The proposed methodology has been applied to the IEEE-33, IEEE-69 nodes standard distribution system for validation by implementation in MATLAB. The paper is arranged as follows: In Section 2, the mathematical modeling and constraints are proposed. Section 3, MABC algorithm descriptions, is presented. In Section 4, the simulation and results are analyzed for five different scenarios and compared with other works mentioned in the literature, and finally conclusions.

2. System Modeling and Methodology

In this paper, the distribution systems will be reconfigured with DG integration to minimize the power losses and improve the voltage profile, taking into account some operation constraints under specific loading. The problem of the distribution network reconfiguration simultaneously with DGs installation is formulated mathematically, as follows:

$$\text{Minimize} \quad f \tag{1}$$

$$f = \Delta P_{loss}^{reconfig.} + \Delta P_{loss}^{DGplac.} \tag{2}$$

Where:
$\Delta P_{loss}^{reconfig.}$: Power loss in case of reconfiguration,

$\Delta P_{loss}^{DGplac.}$: Power loss in case of DG placement,
f: power losses objective function.

The power loss in the branch connected between two buses n+1 and n is calculated by equation “3.”

$$\mathrm{P_{loss}} = \mathrm{r_m}\left[\frac{\mathrm{P^2{}_m+Q^2{}_m}}{|\mathrm{V_m}|^2}\right] \tag{3}$$

And the total power loss, $\mathrm{P_{t\,loss}}$For a distribution network with M branches will be

$$\mathrm{P_{t\,loss}} = \sum_{m=1}^{M} P_{loss} \tag{4}$$

Where P_n *and* Q_nIs the active and reactive power out from bus number n, respectively, and $r_m is$resistance of line section between two nodes n, n+1.

2.1. Power Loss Reduction due to Reconfiguration

Reconfiguration of the distribution system is the best connection for the electric network for power loss reduction, considering some constraints such as voltage profile, feeder current capacity, and radial topology connection. The power loss$P_{loss}^{"}$For branch between two buses for the reconfigured distribution network can be calculated by:

$$P_{loss}^{"} = r_m^{re}\left[\frac{\mathrm{P^{"2}{}_n+Q^{"2}{}_n}}{|\mathrm{V_n}|^2}\right] \tag{5}$$

And the total power loss, $P_{t\,loss}^{"}$for all branches will be

$$P_{t\,loss}^{"} = \sum_{m=1}^{M} P_{loss}^{"} \tag{6}$$

So the net power loss reduction due to reconfiguration is the difference between total power losses before and after reconfiguration, which will be formulated as follows:

$$\Delta P_{loss}^{reconfig} = \sum_{m=1}^{M} P_{loss} - \sum_{m=1}^{M} P_{loss}^{"} \tag{7}$$

2.2. Power Losses Reduction due to DGs Placement

For power loss reduction and voltage profile improvement, the DGs are installed at optimum locations with proper sizes. Let DG be installed at node “n” for a radial network with ”N” nodes, “M” branches, and “μ” is the branches linked to the node n with source. The DG will inject active power. $P_{dg}$and reactive power Q_{dg} To the distribution network. The apparent power “S” at node n, which flows in connected branch m, can be calculated:

$$S = S_{Dn} = \sum_{n=1}^{N} P_{Dn} + jQ_{Dn} \quad (8)$$

And the current without DG at this node from equation "9" will be

$$I_{Dn\ without\ DG} = \left(\frac{S_{Dn}}{V_n}\right)^* \quad (9)$$

The power apparent when DG is placed at node n will be obtained by equation "10":

$$(P_{Dn})_{with\ DG} = (P_{Dn})_{without\ DG} - (P_{dg})_n \quad (10)$$

And the apparent power due to DG placement at node n will be:

$$S_{dgn} = \sum_{n=1}^{N} P_{dgn} + jQ_{dgn} \quad (11)$$

So the total power apparent after DG placement at node n can be calculated as follows:

$$S = S_{Dn} - S_{dgn} \quad (12)$$

And the new current at node n will be

$$I_{Dm\ with\ DG} = \left(\frac{S_{Dn}-S_{dgn}}{V_n}\right)^* \quad (13)$$

From equation 19, the power loss reduction due to DG placement is:

$$\Delta P_{loss}^{DGplac.} = \sum r_m \times (I_{Dm\ with\ DG})^2 \quad (14)$$

We can get the total power loss reduction due to DGs placement in the reconfigured distribution network and put it in equation "2" to get the objective function of the proposed mathematical model [17]. The constraints of the objective function are:

-Voltage at the node is maintained within certain limits

$$V_{n_{min}} \le |V_n| \le V_{n_{max}} \quad (15)$$

Where V_n, $V_{n_{min}}$ and n_{max} are node voltage, minimum node voltage, and maximum node voltage limits, respectively.

-Current in branches maintained within certain limits

$$|I_{n,n+1}| \le |I_{n,n+1}|_{max} \quad (16)$$

The current in the branch m between two nodes n & n+1 is within the limit

DGs installed within limits

$$(P_{Dn})_{min} \le (P_{dg})_n \le (P_{Dn})_{max} (Q_{Dn})_{min} \le (Q_{dg})_n \le (Q_{Dn})_{max} \quad (17)$$

DGs' Active and reactive generated power are between the minimum and maximum limits.

-Network topology is radial, and each load bus must be provided with the required active and reactive power

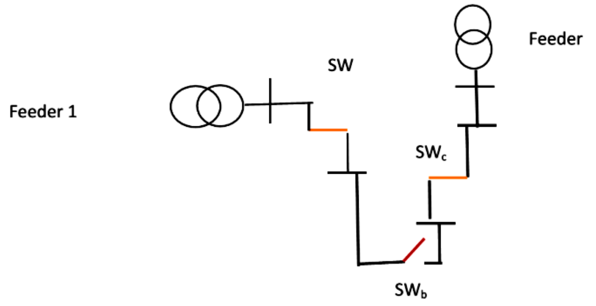

Fig. 1. Show radial network constraint.

3. Proposed Artificial Algorithm

3.1. Artificial Bee Colony (ABC)

In the ABC algorithm, three types of bees, onlooker and scout were must be adjusted for food seeking and processing, where each type in the algorithm has a known function[34]. The task of the employed bees is firstly calculating the available amount of the food source, and after that specifying the number to each of the employed bees. The onlooker bees have the task of choosing good food sources. Finding food sources is the main target of scout bees. The employed bee will be a scout bee if the current food source collected by an employed bee becomes rare. The possible solution is the food source. The quality of the solution is proportional to the food amount, which is the fitness value of the algorithm. The algorithm steps are as follows:

a) Random establishment for food sources :

$$X_{im} = \min X_y + \text{rand}(0,1) \times (\max X_n - \min X_n) \quad (18)$$

Where:

i: food source index number,

m: random index number, X_{im}: set of solutions,

min X_n: n[th] element minimum value,

maxX_n: n[th] element maximum value.

b) Food sources fitness value:

$$\text{if } f_s \ge 0 \rightarrow f_s = \frac{1}{(1+f_s)} \quad (19)$$

$$\text{if } f_s < 0 \rightarrow (1 + |f_s|) \quad (20)$$

Whereas: fitness value at line i of the solution set.

c) New candidate food source creation:

c) New candidate food source creation:

For each of the food sources established, we can apply the following equation to get a candidate food source. After that, a comparison between the fitness values of the new food sources and the fitness values of the old food sources will be done. As a result of the comparison, if the fitness value of the new food source is greater than the old food source, the old one is replaced:

$$V_{im} = X_{im} + \varphi_{im} \times (X_{im} - X_{jm}) \quad (21)$$

Where:

V_{im}: New food source parameter value,

X_{im}: m line selected food source value,

X_{jm}: random neighbor food source value.

b: random neighbor food source index,

$\O_{im}$: two food sources distance change.

d) Better food sources creation:

Apply the following equation to the selected food sources. The fitness values are computed and compared with the old values. If the fitness value improved, the old food source was replaced with the new one.

$$o_s = \frac{f_s}{\sum_j f_s} \quad (22)$$

O_s: on looker bee possible resulted solution,
f_s: selected solution set fitness value,
$\sum_j f_s$: Total solution sets fitness value.

e) In case the current food source cannot be enhanced, that source is canceled and starts again with a new random solution set using the first equation [35].

3.2. Modified Artificial Bee Colony (MABC)

The proposed MABC algorithm was developed in order to solve the complex problem more successfully and more quickly than the ABC algorithm. The MABC algorithm has two additional parameters which not in the ABC algorithm, one of which attaches the scaling factor parameter ratio and the other to the ratio [36].In the ABC algorithm, a single food source is updated, while in the MABC algorithm, multiple food sources are determined due to the ratio of modification. To get the modification rate, we apply the following equations:

If R_{im}< modification rate, where R_{im} is a randomly produced value, then

$$V_{im} = X_{im} + \varphi_{im} \times (X_{im} - X_{jm}) \quad (23)$$

$$\text{Else } V_{im} = Xim \quad (24)$$

In the MABC, the value range produced is related to the scalar factor parameter changing, so it will be in the range of [-SF, SF]. Where the number randomly produced for the ABC algorithm is in the range of [-1,1] [37]. The flow chart of the program is shown in Figure 2.

4. Simulation and Results

To determine the optimal locations and size of DGs in a reconfigured distribution system, the proposed MABC algorithm and solution methodology are tested on - 33-IEEE - 66 buses radial distribution network with tie lines, where data loads are given in [38]. For each tested network, five scenarios are studied to clarify the reliability of the proposed algorithm.
Scenario 1: Distribution system base case.
Scenario 2: Reconfigured distribution system.
Scenario 3: Distribution system with DGs.
Scenario 4: DGs placement after network reconfiguration
Scenario 5: Reconfigured the distribution system with DGs simultaneously.

4.1. Tested Distribution System 33-Nodes

The 33-node 12.66 kV radial feeder in Figure 3 has 33 nodes, 37 branches,3.72 + j2.3 MVA total loads[38]. The simulation results for applying the proposed MABC algorithm on33-node test system for the five scenarios are shown in Table 1 and the voltage profile in Figure 4. In the initial configuration (scenario 1), there are five open switches of 33-34-35-36-37 and 32 normally closed switches with a minimum voltage of 0.9138 p.u. at bus 18 and 202.68 kW power loss. In scenario 2, with optimal reconfiguration with the proposed MABC algorithm, the power loss was reduced to 139.5 with 31.18 % loss reduction, and the minimum node voltage improved to 0.939 p.u. In case of DGs placement only (scenario 3), the power loss reduced to 71.2 with 64.87 % loss reduction, and the minimum node voltage improved to 0.978 p.u. When DGs were installed after optimal feeder reconfiguration (scenario 4), the power loss reduced to 57.3 with 71.7 % loss reduction, and the minimum node voltage improved to 0.985 p.u. For the fifth scenario, where DGs are installed simultaneously with feeder reconfiguration, the power loss reduced to 53.04 with 73.78 % loss reduction, and the minimum node voltage improved to 0.987 p.u.

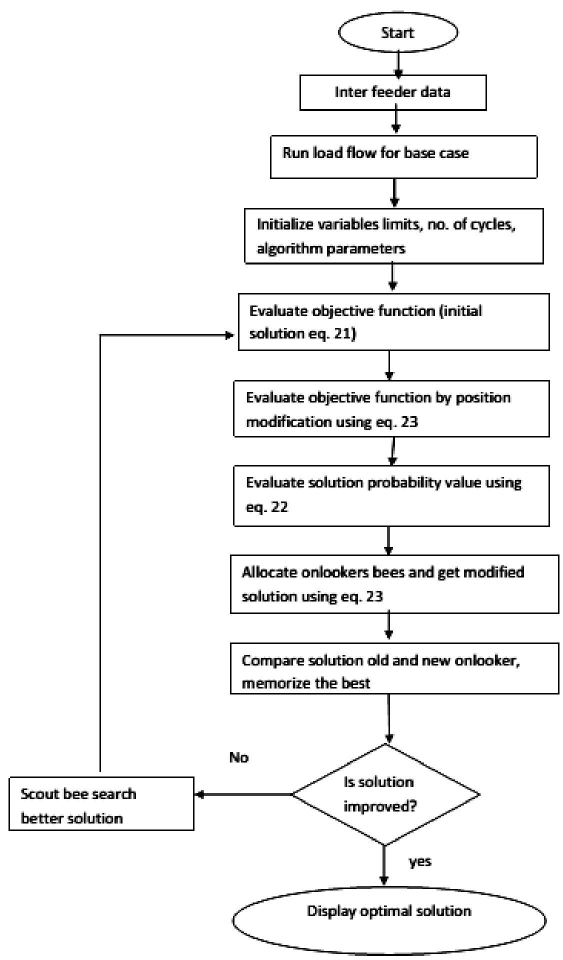

Fig. 2: Flow chart of the proposed MABC. Algorithm.

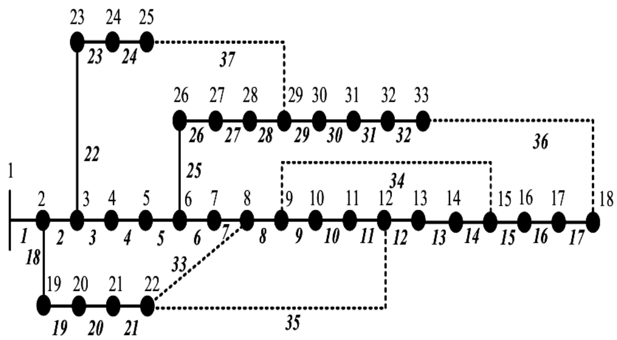

Fig. 3: 33-Nodes Distribution Network.

Table 1. Simulation results for 33- 33-node system, all scenarios.

Item	Opened switches	Power loss (kW)	Min, voltage (node)	DGs size MW (location)	Power loss reduction (%)
Scenario 1	33-34-35-36-37	202.68	0.9138	----	---
Scenario 2	7-9-14-32-37	139.5	0.939	-----	31.17
Scenario 3	33-34-35-36-37	71.2	0.978	0.96 (30), 1.1 (24), 0.95 (8)	64.87
Scenario 4	7-9-14-32-37	57.3	0.985	0.921 (8), 0.984 (30), 0.953 (32)	71.7
Scenario 5	7-10-14-28-32	53.04	0.987	0.641(18), 1.521(25), 0.7076(32)	73.78

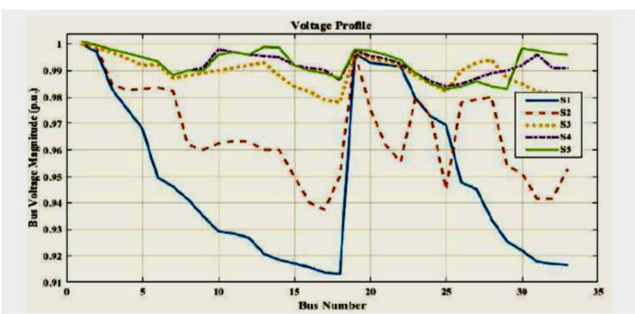

Fig. 4. Voltage profile for the 33-node system for the five scenarios.

- In Table 2, a comparison with the proposed methodology with other works with variant algorithms such as GA [26], HSA[27], RGA [28], FWA[29], MPGSA[30], UVDA[31], SFSA [32], and CSA [33] is presented.

- In scenario 1, the results are the same for all algorithms
- In scenario 2, the best results for power loss are by the proposed MABC algorithm and the SFS, MPGSA algorithms. The best results for minimum voltage are FWA, CSA, and the proposed MABC, respectively.
- In scenario 3, the best results for power loss are by the proposed MABC algorithm and the SFSA algorithm. The best results for minimum voltage are the proposed MABC algorithm and CSA algorithm.
- In scenario 4, the best results for power loss are by the proposed MABC algorithm, CSA, and SFSA, respectively. The best results for minimum voltage are the proposed algorithm.
- In scenario 5:the best results for power loss 53.04 kW and minimum voltage 0.987 p. u. are presented by the proposed MABC algorithm as shown in Table 2.

By comparison with variant algorithms in other works for the IEEE-33 network, the minimum power loss 53.04 kW with optimal improvement in voltage 0.987 p.u. is achieved by simultaneous DGs 0.641 MW (node 18), 1.521 MW (node 25), 0.7076 MW (node 32) placement with electrical network reconfiguration (open switches 7-10-14-28-32) using the proposed MABC algorithm.

Table 2: comparison results for 33-node standard feeder.

Item	Scenarios	GA [26]	CSA [33]	RGA [28]	HSA [27]	FWA [29]	UVDA [31]	SFSA [32]	MPGSA [30]	Proposed MABC
Power loss kW	1	202.68	202.68	202.68	202.68	202.68	202.68	202.68	202.68	202.68
	2	141.6	139.9	139.9	146.4	139.9	139.6	139.5	139.5	139.5
	3	100.1	74.26	97.6	96.76	88.86	74.21	71.47	95.42	71.2
	4	98.36	58.79	98.23	97.13	83.81	66.6	58.88	92.87	57.3
	5	75.13	63.69	74.23	73.05	67.11	57.28	55.28	72.23	53.04
Minimum Voltage	1	0.914	0.914	0.914	0.914	0.914	0.914	0.914	0.914	0.914
	2	0.931	0.941	0.932	0.934	0.941	0.938	0.938	0.934	0.939
	3	0.961	0.978	0.969	0.967	0.968	0.962	0.959	0.969	0.978
	4	0.951	0.980	0.948	0.948	0.961	0.976	0.948	0.974	0.985
	5	0.977	0.979	0.969	0.970	0.971	0.968	0.972	0.972	0.987

4.2. Tested Distribution System 69-Nodes

The 69-node 12.66 kV radial feeder in Figure 5 has 69 nodes, 73 branches with 224.89 kW power losses. The simulation results for applying the proposed MABC algorithm on a 69-node test system for the five scenarios are shown in Table 3 and the voltage profile in Figure 6.

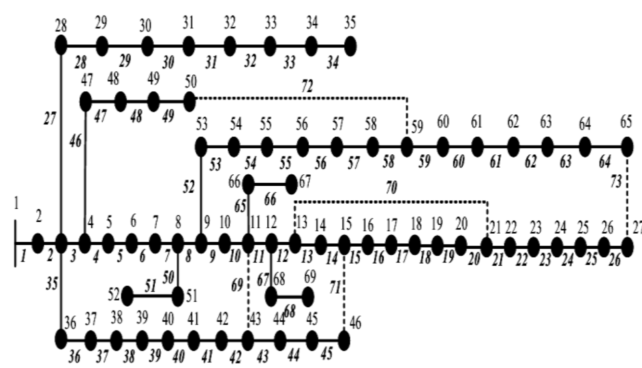

Fig. 5. 69-Nodes Distribution Network.

In the initial configuration (scenario 1), there are five open switches of 69,70,71,72,73, and 68 normally closed switches with a minimum voltage of 0.9092 p.u. at bus 65.

In scenario 2, with optimal reconfiguration with the proposed MABC algorithm, the power loss was reduced to 98.15 kW with 56.35 % loss reduction, and the minimum node voltage improved to 0.949 p.u. In case of DGs placement only (scenario 3), the power loss reduced to 70.98 kW with 68.4 % loss reduction, and the minimum node voltage improved to 0.978 p.u. When DGs were installed after optimal feeder reconfiguration (scenario 4), the power loss reduced to 36.1 kW with 84 % loss reduction, and the minimum node voltage improved to 0.983 p.u.

For the fifth scenario, where DGs are installed simultaneously with feeder reconfiguration, the power loss reduced to 34.3 kW with 84.8 % loss reduction, and the minimum node voltage improved to 0.987 p.u.

Table 3 Simulation results for 69-node system, all scenarios.

Item	Opened switches	Power loss (kW)	Min, voltage (node)	DGs size MW (location)	Power loss reduction (%)
Scenario 1	69-70-71-72-73	224.89	0.9092	----	---
Scenario 2	5-6-12-20-61-69	98.15	0.949	-----	56.35
Scenario 3	69-70-71-72-73	70.98	0.978	0.52(18), 0.751 (50), 1,76 (61)	68.4
Scenario 4	14-57-61-69-70	36.1	0.983	0.54 (12), 1.2 (61), 0.695 (64)	84
Scenario 5	13-18-24-56-69	34.3	0.987	0.374 (24), 0.39 (32), 1.6768 (61)	84.8

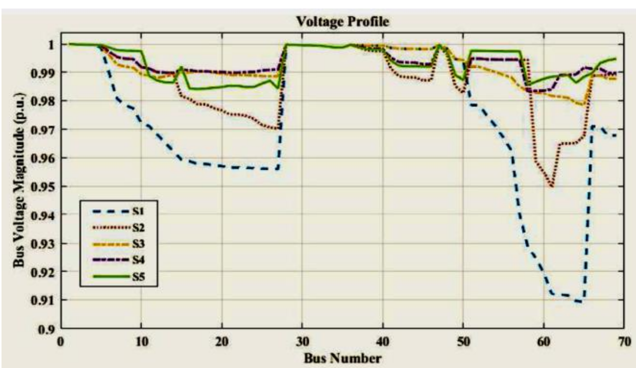

Fig. 6. Voltage profile for a 69-node system for the five scenarios.

In Table 4, a comparison of the proposed methodology with other works with variant algorithms mentioned in the literature is presented.

Table 4. Comparison results for 69-node standard feeder

Item	Scenario.	GA [26]	CSA [33]	RGA [28]	HAS [27]	FWA [29]	UVDA[31]	Proposed MABC
Power loss kW	1	224.89	224.89	224.89	224.89	224.89	224.89	224.89
	2	103.3	98.59	100.3	99.35	98.95	98.58	98.15
	3	88.5	72.44	87.65	86.77	77.85	72.63	70.98
	4	54.53	37.23	52.34	51.3	37.23	37.84	36.1
	5	46.5	40.5	44.23	40.3	40.49	37.1	34.3
Minimum Voltage p.u.	1	0.909	0.909	0.909	0.909	0.909	0.909	0.909
	2	0.941	0.946	0.943	0.943	0.946	0.949	0.949
	3	0.969	0.973	0.968	0.968	0.974	0.969	0.978
	4	0.94	0.982	0.961	0.962	0.983	0.98	0.983
	5	0.973	0.986	0.974	0.974	0.986	0.982	0.987

In scenario 1, the results are the same for all algorithms in the initial configuration.
In scenario 2, the proposed MABC algorithm achieved the best results for power loss of 98.15 kW, while the best results for minimum voltage of 0.949 are achieved by UVDA and the proposed MABC algorithms.
In scenario 3, the best results for power loss are 70.98 kW achieved by the proposed MABC algorithm, and the best results for minimum voltage are 0.978 by the proposed MABC algorithm.

In scenario 4, the best results for power loss are 36.1 kW by the proposed MABC, and the best results for minimum voltage are 0.983 by FWA and the proposed algorithm.
In scenario 5:the best results for power loss and minimum voltage, 34.3 kW, 0.987 p. u. are achieved by the proposed MABC algorithm.

By comparison with variant algorithms in other works for the IEEE-69 network, the minimum power loss 34.3kw with optimal improvement in voltage 0.987 p.u. is achieved by simultaneous DGs 0.374 MW(node 24), 0.39 MW (node 32),1.6768 MW (node 61) placement with electrical network reconfiguration (open switches 13-18-24-56-69) using the proposed MABC algorithm.

5. Conclusion

In this paper, a mathematical model for DGs placement in the reconfigured network problem and an optimization technique based on MABC were proposed to reduce the electric network power losses and improve the network voltage profile. To determine the optimal locations and size of DGs in a reconfigured distribution system, the proposed MABC algorithm and solution methodology are tested on the IEEE-33, IEEE-66 buses radial distribution network. For each tested network, five scenarios are studied: Distribution system base case, Reconfigured distribution system only, Distribution system with DGs only, DGs placement after network reconfiguration, and Reconfigured distribution system with DGs simultaneously. The results obtained and analysis for the two tested feeders show that the optimal solution of the problem is achieved by simultaneous DGs placement with electrical network reconfiguration. By the proposed MABC algorithm, the optimal solution when implementation on the IEEE – 33, IEEE-69 (scenario 5) are: simultaneous DGs 0.641 MW (node 18), 1.521 MW (node 25), 0.7076 MW (node 32) placement with electrical network reconfiguration (open switches 7-10-14-28-32) and simultaneous DGs 0.374 MW(node 24), 0.39 MW (node 32),1.6768 MW (node 61) placement with electrical network reconfiguration (open switches 13-18-24-56-69) respectively. By comparison with CSA, RGA, GA, FWA, UVDA, and HSA algorithms in other works, the solution with the proposed MABC algorithm is the optimum solution considering voltage profile improvement and power loss reduction.

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