Active and Reactive Power loss Minimization Along with Voltage profile Improvement for Distribution Reconfiguration

Original Scientific Paper

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Abstract *– Optimal distribution network reconfiguration (DNR), distributed generations location and sizing (DGs-LS), tap changer adjustment (TCA), and capacitors bank location and sizing (CAs-SL) are different methodologies used to reduce loss and enhance the voltage profile of distribution systems. DNR is the process of changing the network topography by changing both sectionalized and tie switch states. The optimal location looks to find the optimal setting of the DG and CA within the distribution network. Optimal size seeks to find the optimal output generation of both DG and CA. The TCA looks to find the optimal position for TC. These methods are challenging optimization problems and resort to meta-heuristic techniques to find a globally optimal solution. This paper presents a new methodology with which to simultaneously solve the problem of DNR, DGs-LS, TCA, and CAs-SL in distribution networks. This work aims to minimize active and reactive power losses, including voltage profile improvement using a multi-objective decision approach. The firefly algorithm (FA) and analytic hierarchy process (AHP) are used to optimize the fitness function and determine the function weight factors through the use of MATLAB software. Several scenarios were considered on the IEEE 69-bus network. In terms of active power and reactive losses, reductions in the test system of 96.16% and 92.7%, respectively, were achieved, evidencing the positive impact of the proposed methodology on distribution networks.*

Keywords*: Weight factors, power loss, reconfiguration, DG allocation and sizing, Capacitor location and sizing, Tap changer adjustment*

1. INTRODUCTION

Minimizing energy consumption is important for ensuring power quality and system efficiency [1, 2]. This has led researchers to study the operation and design of power systems using different supply sources in the network. Therefore, different methods have been used to reduce energy consumption in the distribution power system by reducing power loss. The most famous methods are network reconfiguration, DG location and sizing, tap changer adjustment position, and capacitor location and sizing [3-5]. The distribution network reconfiguration (DNR) process can be defined as the process of changing the network topography structures according to changing the status of both tie and sectionalizing switches [6]. This improves specific conditions such as reducing power loss, enhancing the reliability of the network, and improving the voltage profile [7, 8]. In [9], PSO with a discrete version was used for load balancing during DNR. Moreover, in [10], the DNR problem was solved using GA to reduce power losses as well as improve the load index and voltage profile. In [11], NR was used to maximize loadability and improve the voltage profile of the radial network, which led to an increase in network reliability. In [12], NR was applied to reduce reactive power loss to improve both voltage stability and loadability using a two-stage algorithm.

One of the most well-known methods to minimize loss is combining both DNR and DG location and sizing methods [13]. DG location means the best sitting of the DG within the distribution network, while DG sizing expresses the best output generation from the DG [14, 15]. The authors in [16] dealt, simultaneously, with DNR and DG sizing and location problems in order to optimize power loss. In [17], the authors used a firework algorithm to find the optimal DG sizing and location integrated with optimal network configuration based on minimum power loss. Similar objectives were achieved in [18] using EP and GA. In [19, 20], a discrete artificial bee colony method was used based on the continuation power flow methodology in order to achieve the maximum loadability of the network. In [21, 22], NR integrated with DG through a two-stage hierarchical optimization methodology was proposed to trade between reducing power loss and maximum loadability.

Another well-known method to minimize loss is combining both DNR and CA location and sizing methods [23]. CA location means the best sitting of the CA within the distribution network, while CA sizing expresses the best output generation from the CA [24]. This method aims to reduce power loss, voltage fluctuations, and the operating cost since the capacitor output is reactive power that improves the voltage profile [25]. A lot of optimization techniques have been presented for network reconfiguration considering CA sizing and location. In [26], the authors solved this problem using harmony search and simulated annealing algorithms. In [27, 28], the authors also solved this problem using the ant colony algorithm, Big Bang method, and genetic algorithm. In [29], grey wolf optimization integrated with the PSO method was presented to solve the same problem. The main objectives within these studies were reduced investment cost, annual loss of energy cost, maintenance and operation cost, and switching cost. In [30], GA was used to optimize the CA location and size and optimize the sequence of loop selection for minimizing energy losses. The presented methodology was tested on a real 77-bus system with different load patterns.

Another different method that is also presented in the published works is tap changer adjustment (TCA). TCA is a mechanism that allows transformers to find the best position of the transformer's turn ratios that achieve the best voltage profile [31]. The work in [32] addressed the reconfiguration problem after the power cut caused by the cut of a branch of the system. The work presented an approach that handled the reconfiguration process simultaneously with transformer tap changer adjustments. The presented approach considered the AC power model, network operation topology, and both voltage and load limitations. The results obtained showed that the presented approach could find the best solution; it presents the overloaded branches and the minimum number of buses that were outside of operation. The authors in [33] proposed network reconfiguration with TCA integrated into the DG sizing method to minimize network power loss using the imperialist competitive algorithm. The proposed method indicated an improvement in the voltage profile and power loss reduction compared to other algorithms. In [34], a simultaneous method combined with DNR with DGs-LS, including TCA, was presented. The method proposed a multi-objective decision methodology that obtained the maximum loadability and best voltage profile as well as minimum power loss using the FA.

The main contribution of this paper is the simultaneous combination of the most famous methods used to improve the performance of a distribution system. The methods represent network reconfiguration, DG location and sizing, tap changer adjustment, and capacitor location and sizing. The remainder of this paper is organized as follows: Section II presents the mathematical modeling proposed; Section III presents the proposed approach; Section IV presents the test system and results in detail; and Section V presents the conclusions.

2. MATHEMATICAL MODELING

This section presents the proposed fitness function that solves the optimal DNR problem and optimal DGs-LS, including optimal TCA, along with optimal CAs-LS. In addition, we also present all the constraints and limitations the fitness function fulfills. The function looks to minimize both active and reactive power losses simultaneously while improving the voltage profile index.

2.1. FITNESS FUNCTION

The fitness function is described as follows:

$$\text{Minimize } F = (\omega_1 P_{loss} + \omega_2 Q_{loss} + \omega_3 \text{ IVD}) \quad (1)$$

where ω_1, ω_2, and ω_3 are the fitness function (F) weight factors. P_{loss} is the active power loss. Q_{loss} is the reactive power loss. The fitness function is set to be unity to minimize all the function terms. The active power loss (P_{loss})is taken as the ratio of the active power loss after and before optimization, as follows [35]:

$$P_{loss} = \frac{P_{loss}^{opt}}{P_{loss}^{0}} \quad (2)$$

where P_{loss}^{opt} is the active power loss after optimization. P_{loss}^{0} is the active power loss before optimization.

$$P_{loss} = \sum_{N=1}^{M} (R_N \times |I_N|^2) \quad (3)$$

where R_N is the resistance in the branch N, I_N is the branch current, and M is the branch number.

Moreover, the reactive Power loss (Q_{loss})is taken as the ratio of the reactive Power loss after and before optimization, as follows [35]:

$$Q_{loss} = \frac{Q_{loss}^{opt}}{Q_{loss}^{0}} \quad (4)$$

where Q_{loss}^{opt} is the reactive power loss after optimization. Q_{loss}^{0} is the reactive power loss before optimization.

$$Q_{loss} = \sum_{N=1}^{M} (X_N \times |I_N|^2) \quad (5)$$

where X_N is the reactance in branch N.

Voltage profile index (IVD): this index penalizes the size location pair, which gives higher voltage deviations from the nominal voltage. In this way, the closer the index is to zero, the better the network performance is.

The IVD is addressed as follows:

$$\text{IVD} = \max_{i=2}^{n}\left(\frac{|\overline{V}_1|-|\overline{V}_i|}{|\overline{V}_1|}\right) \tag{6}$$

Where V_i is the bus voltage; V_1 is the nominal voltage; and n is the bus number.

2.2. LIMITATIONS AND CONSTRAINTS

All limitations and constraints that the fitness function should satisfy are as follows:

Distributed generator and Capacitor capacity

$$P_i^{min} \le P_{DG,i} \le P_i^{max} \tag{7}$$

$$Q_i^{min} \le Q_{CAP,i} \le Q_i^{max} \tag{8}$$

where $P_{DG,i}$ is the DG size at bus i; P_i^{max} and P_i^{min} are the higher and the lower DG capacities, respectively. $Q_{CAP,i}$ is the capacitor size at bus i; Q_i^{max} and Q_i^{min} are the higher and the lower capacitor capacities, respectively.

- Power injection

$$\sum_{i=1}^{k} P_{DG,i} < \sum_{n}^{nbus}\left(P_{Load_n}\right) + P_{loss} \tag{9}$$

$$\sum_{i=1}^{k} Q_{CAP,i} < \sum_{n}^{nbus}\left(Q_{Load_n}\right) + Q_{loss} \tag{10}$$

where k is the DG number; $nbus$ is the bus number; P^{n}_{Load} is the active power load at bus n; and Q^{n}_{Load} is the reactive power load at bus n. This means that there are no active or reactive powers flowing from DGs or capacitors to the grid.

- Power balance

$$\sum_{i=1}^{k} P_{DG,i} + P_{Substation} = P_{Load} + P_{loss} \tag{11}$$

$$\sum_{i=1}^{k} Q_{CAP,i} + Q_{Substation} = Q_{Load} + Q_{loss} \tag{12}$$

where $Q_{CAP,i}$ is the capacitor size at bus i; $S_{Substation}$ is the main substation apparent power supplied. Total power must fitful the principle of equilibrium. Thus, the supply of power must be equal to its demand.

- Voltage magnitude

$$0.95 \le V_{bus} \le 1.05 \tag{13}$$

where V_{bus} is the bus voltage, which is within the voltage limits (0.95 to 1.05) p.u.

- Radial configuration

At all times, the network must save the radiality configuration.

- Load connection

After the reconfiguration, all distribution buses must be connected to a power source.

3. PROPOSED APPROACH

This section presents the proposed simultaneous methodology to solve the optimal DNR problem and optimal DGs-LS, including optimal TCA, integrated with optimal CAs-LS using the AHP and FA techniques. The proposed methodology looks to minimize both active and reactive power losses and minimize the voltage profile index.

3.1. ANALYTIC HIERARCHY PROCESS

The main fitness formula is controlled by an AHP multi-objective decision approach that determines the weights of the formula factors. The AHP is an effective and practical approach used to solve multicriteria decision-making problems, and it was introduced by Thomas L. Saaty in [36, 37]. The AHP seeks to simplify complex problems by deconstructing them into simple parts. This occurs by taking a fraction of the overall decision problem that allows the decision maker to focus on different criteria based on the importance of said criteria. There are three stages in the AHP: determining the decision-making problem by constructing the hierarchy and finally evaluating the factors in the stairway. The evaluation of the factors of the stairway is then compared using a scale of numbers from one to nine [38]. Table 1 shows the relative importance matrix used in the AHP for various indices.

Table 1. Matrix of relative importance

Standard	Numeric-Rating	Reciprocal
Equality–Importance	1	1
Equality to Moderately	5	0.2
Moderately Important	7	0.143

Table 2 shows the weights obtained from the AHP method. The details of the AHP are illustrated in Fig. 1. For more explanation, this work focuses on different criteria, namely active power loss, reactive power loss, and voltage profile. The relative importance of the active power loss is equal to one (equality–importance), reactive power loss is equal to five (equality to moderately), and the voltage profile is equal to seven (moderately important). Based on these values, the weights obtained are 0.632819 for active power loss, 0.301806 for reactive power loss, and 0.065375 for voltage profile. This means that if the relative importance of the different criteria differs, the weight values directly differ.

Table 2. AHP approach weight factors

Criteria	Active Power Loss	Reactive Power Loss	Voltage profile	Total =∑Row	Weights = Total/ Sum
Active power loss	1	5	7	13	0.632819
Reactive power loss	0.2	1	5	6.2	0.301806
Voltage profile	0.143	0.2	1	1.343	0.065375
Sum				20.543	1

3.2. TAP CHANGER ADJUSTMENT

In the presented methodology, there are 17 values representing the TC positions, as shown in Fig. 2. These positions correspond to bus voltage, which changes from -5 to +5 % [39]. This makes the lower and upper bus voltage limits 0.95 p.u and 1.05 p.u, respectively [40].

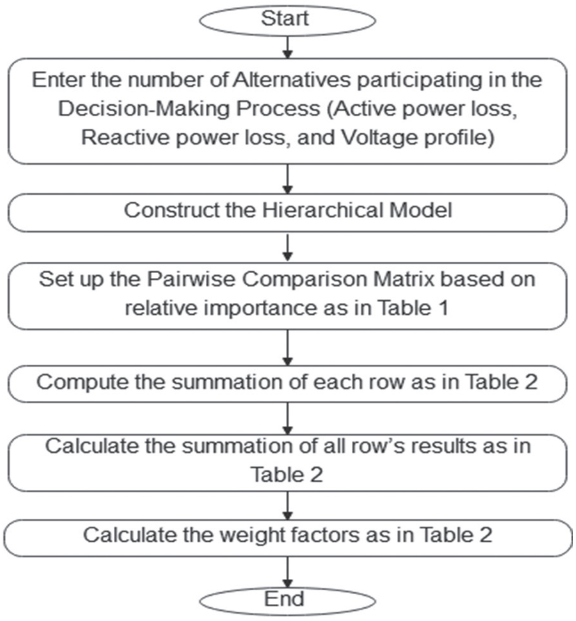

Fig. 1. Flow chart of AHP

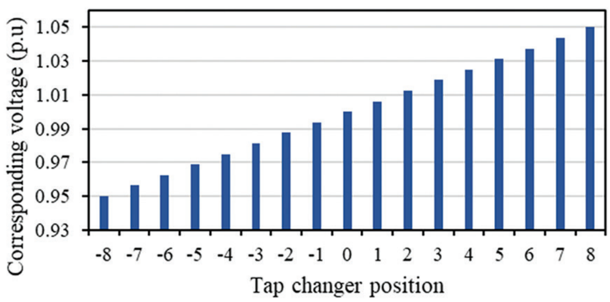

Fig. 2. Tap changer position corresponding to bus voltage (p.u)

3.3. FIREFLY ALGORITHM (FA)

The firefly algorithm is a nature-inspired meta-heuristic method that has gained popularity due to its capability to be involved in transactions with global non-linear optimization problems [41]. The FA is a method inspired by the attitude of fireflies and their different shining types [41]. All fireflies are attracted to flies that achieve strong flashing brightness. Therefore, the flashing brightness is exactly proportional to attraction. Moreover, attraction is proportional inversely to the space between fireflies. Flies will move to a specific location in the case where all fireflies have the same brightness intensity. The steps to implement the FA to solve the OP-DNR problem and OPDGs-LS, including TCA integrated with OPCAs-LS, are proposed as follows:

- Determine the constant values of the FA, population, and iteration size.
- Set the data input, such as the resistance and reactance values of the lines, active and reactive load of the buses, initial values of the bus voltages, and TCA locations.
- Define the weight factors based on the AHP technique, as in Table 2.
- Generate initial FA populations randomly (Y) that achieved all the constraints and imitations that present the tie switches of the distribution (S), DG sizing (DGS), DG location (DGL), CA sizing (CAS), CA location (CAL), and TCA position (TP). All FA elements are set simultaneously, as is presented in the following equation:

$$Y = \begin{bmatrix} S_{11} & S_{12} \cdots S_{1n} & DG_{S11} & DG_{S12} \cdots DG_{S1k} & DG_{L11} & DG_{L12} \cdots DG_{L1k} & CA_{S11} & CA_{S12} \cdots CA_{S1k} & CA_{L11} & CA_{L12} \cdots CA_{L1k} & T_{P1} \\ S_{21} & S_{22} \cdots S_{2n} & DG_{S21} & DG_{S22} \cdots DG_{S2k} & DG_{L21} & DG_{L22} \cdots DG_{L2k} & CA_{S21} & CA_{S22} \cdots CA_{S2k} & CA_{L21} & CA_{L22} \cdots CA_{L2k} & T_{P2} \\ \vdots & \vdots \cdots \vdots & \vdots & \vdots \cdots \vdots & \vdots & \vdots \cdots \vdots & \vdots & \vdots \cdots \vdots & \vdots & \vdots \cdots \vdots & \vdots \\ S_{m1} & S_{m2} \cdots S_{mn} & DG_{Sm1} & DG_{Sm2} \cdots DG_{Smk} & DG_{Lm1} & DG_{Lm2} \cdots DG_{Lmk} & CA_{Sm1} & CA_{Sm2} \cdots CA_{Smk} & CA_{Lm1} & CA_{Lm2} \cdots CA_{Lmk} & T_{Pm} \end{bmatrix} \quad (14)$$

where n is the NO of tie switch; k is the NO of DGs and CAs; and m is the size of the population.

- The iteration process is started by analyzing the distribution load flow using Newton–Raphson methodology to compute the distribution active and reactive power loss values, as well as the values of minimum and maximum bus voltage.
- The value of the fitness function is estimated for all populations of matrix Y related to Equation (1).
- Populations are sorted based on their light intensity in ascending order, and then the lower value is kept, which presents the top light intensity.
- The elements of the Y matrix related to the FA technique are updated, taking into account the constraints and limitations. In addition, the motion is arranged and updated in ascending form related to the following formulas:

$$\beta(r) = \beta_0 e^{-\gamma r^2} \quad (15)$$

where γ is the light absorption coefficient, and β_0 is the attractiveness when r=0 ; r is the 2 FAs' space.

$$r_{lj} = \|y_l - y_j\| = \sqrt{\sum_{k=1}^{d} (y_{l,k} - y_{j,k})^2} \quad (16)$$

where r_{lj} is the Cartesian space between l and j FAs, which presents the Y matrix rows; d is the optimized numbers of the parameters; and $y_{l,k}$ and $y_{j,k}$ represent the k_{th} component of the Cartesian coordinates y_l and y_j of FAs l and j, respectively.

$$y_{l,k} = \beta_0 e^{-\gamma r_{lj}^2} (y_{j,k} - y_{l,k}) + \alpha(\text{rand} - 0.5) + y_{l,k} \quad (17)$$

where the first equation term $x_{l,k}$ presents influence by attractiveness (when γ=1); the second equation term presents the random item related to α; and the third term presents the motion of FAs that FA l is attracted to brighter FA j. The random number rand (1) presents a random number [0, 1].

- The prior operation from steps (5 to 8) is repeated until the maximum iteration number is reached.

- The loop is ended, and the optimal solution is kept that presented the distribution final configuration, CA's location and size, DG's location and size, and TCA location. This optimal solution obtained:
    1. Minimum active power loss.
    2. Minimum reactive power loss.
    3. Best voltage profile index.
- The previous process is re-run one hundred times to check the FA's robustness.

Fig. 3 illustrates the previous methodology in a simple flow chart that summarizes the function of both the FA and AHP methods in solving the optimal DNR and optimal DGs-LS, including optimal TCA integrated with the optimal CAs-LS problem.

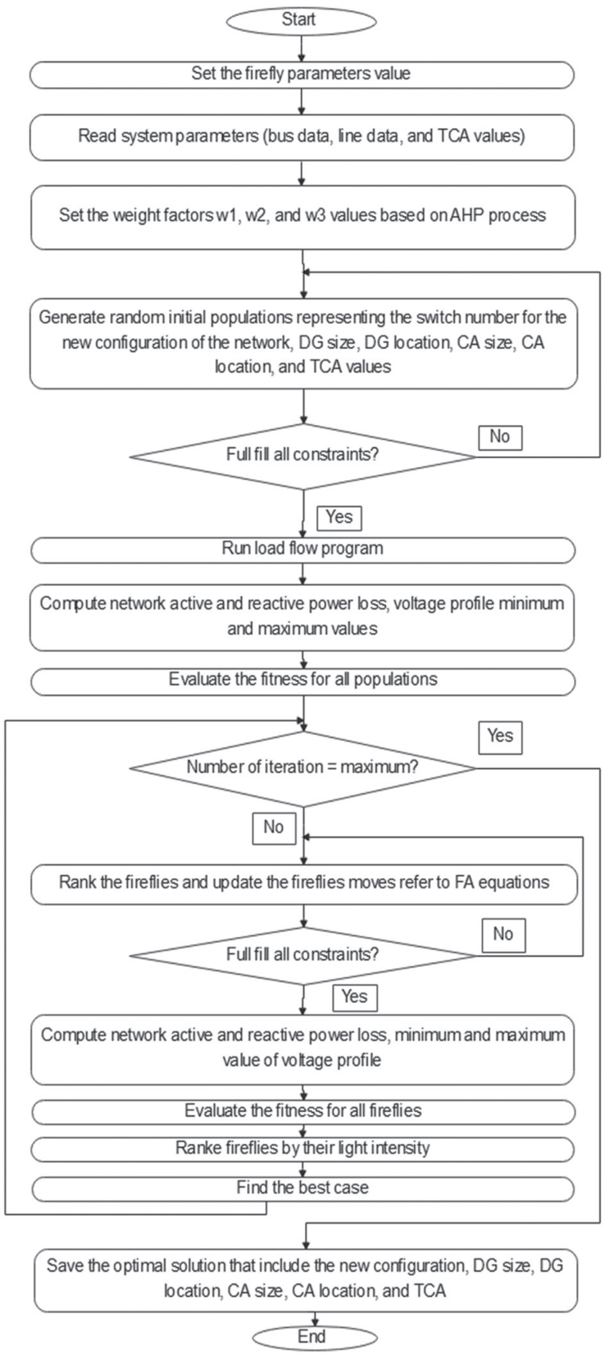

Fig. 3. Flowchart of the proposed approach

4. TEST SYSTEM AND RESULTS

The proposed methodology in this work was implemented and solved using MATLAB software. Simulation codes were carried out on a laptop with an Intel CORE i7 processor. Each code was run 100 times for 100 population sizes and 300-time iterations.

To test the approach's superiority, different scenarios were considered:

Scenario 1: Represent the initial form. The original network system without any modifications.

Scenario 2: Represent the optimal simultaneous distribution network reconfiguration (DNR) and DG location and sizing.

Scenario 3: Represent the optimal DNR simultaneously with DGs-LS, including tap changer adjustment (TCA).

Scenario 4: Represent the optimal DNA simultaneously with DGs-LS, including TAP, and incorporating capacitor bank location and sizing CAs-SL.

The IEEE 69-bus distribution network was used to test the power of the proposed methodology, as shown in Fig. 4 [35].

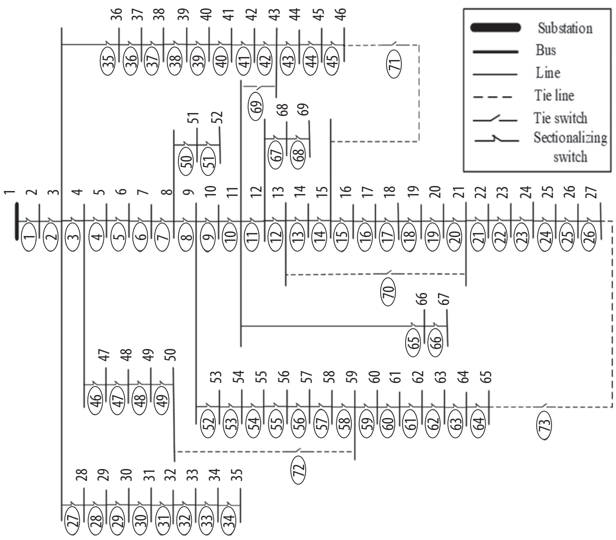

Fig. 4. IEEE 69-bus distribution system

The system data are available in [42]. This system consists of 73 branches, 5 tie switches, and 68 sectionalizing switches. In the initial form (Scenario 1), switches 69 to 73 are open. The system nominal voltage is 12.66 kV, with a minimum voltage magnitude of 0.9092 p.u. The system's apparent power demand is (3, 802.19+j2, 694.6) kVA. The active and reactive power losses are 224.99 kW and 39.16 kVAR, respectively. The DG in this work was assumed to be a mini-hydro generation. The maximum capacity for DG was 2 MW. Furthermore, the maximum capacity for the capacitor was 2 MVAR. The obtained optimal solutions were proposed to be the tie switch, DG location and size, capacitor location and size, and tap changer adjustment position. These were all simultaneously determined.

4.1. IMPACT OF THE PROPOSED METHODOLOGY ON POWER LOSSES

This section of the paper focuses on reductions in active and reactive power loss and improvement in bus voltage. Table 3 summarizes the results obtained from all of the scenarios.

Table 3. Distribution network system features

Optimization technique	Scenario 1	Scenario 2	Scenario 3	Optimization technique
Tie switch	69, 70, 71, 72, 73	13, 12, 62, 10, 57	69, 70, 13, 55, 63	21, 20, 7, 13, 55
DG location (DG sizing (MW))	-------	22 (0.5005) 16 (0.3991) 61 (1.5016)	22 (0.405) 16 (0.213) 61 (1.489)	62(0.7858) 61(1.1103) 51(0.7280)
CA location (CA sizing (MVAR))	-------	-------	-------	51(0.5153) 27(0.2634) 61(0.9992)
Tap changer	-------	-------	1.0194	1.04092
Fitness	-------	0.22785	0.20233	0.046091
Active power loss(kW)	224.557	39.16	36.58	8.621
Reactive power loss (kVAR)	102	38.64	33.315	7.445
Active power reduction (%)	-------	82.56	83.71	96.16
Reactive power reduction (%)	-------	62.12	67.34	92.7
Minimum bus voltage	0.9093	0.980353	1.019367	1.033656
Maximum bus voltage	1	1	1.037505	1.041507

Scenario 1 represents the initial form. The tie switches were 69, 70, 71, 72, and 73. The active and reactive power losses were 224.557 kW and 102 kVAR, respectively. The minimum and maximum bus voltages were 0.9093 and 1.038 pu, respectively. Scenario 2 represents the optimal distribution network reconfiguration of DNR simultaneously with DG location and sizing, where better results were obtained than those in Scenario 1. In Scenario 2, the tie switches changed to 13, 12, 62, 10, and 57. The DG locations were set on buses 22, 16, and 61 with DG sizes of 0.5005 kW, 0.3991 kW, and 1.5016 kW, respectively. The fitness value was 0.22785. Both active/reactive power loss was reduced to 39.16 kW and 38.64 kVAR, respectively, compared to the initial form. The reductions in both active/reactive power loss were 82.56% and 62.12%, respectively. The bus voltages minimum and maximum values improved to 0.980353 and 1 pu, respectively.

Scenario 3 represents the optimal DNR simultaneously with DGs-LS integrated with tap changer adjustment (TCA). In Scenario 3, the tie switches changed to 69, 70, 13, 55, and 63. The DG locations were set on buses 22, 16, and 61 with DG sizes of 0.405 kW, 0.213 kW, and 1.489 kW, respectively. The fitness value was 0.20233 with a tap changer adjustment position of 1.0194. The reductions in active and reactive power losses were reduced to 36.58 kW and 33.315 kVAR, respectively. Both active/reactive power loss reductions were 83.71% and 67.34%, respectively. The bus voltages minimum and maximum values improved to 1.019367 and 1.037505 pu, respectively. This means that Scenario 3 obtained better results than those achieved in Scenarios 1 and 2.

Scenario 4 represents the optimal DNA simultaneously with optimal DGs-LS, including optimal TAP, and incorporating optimal capacitor bank location and sizing CAs-SL. In Scenario 4, the tie switches changed to 21, 20, 7, 13, and 55. The DG locations were set on buses 62, 61, and 51 with DG sizes of 0.78581 kW, 1.11037 kW, and 0.72809 kW, respectively. The capacitor's locations were set on buses 51, 27, and 61 with capacitor sizes of 0.51531 kVAR, 0.26349 kVAR, and 0.99929 kVAR, respectively. The fitness value was 0.046091 with a TCA position of 1.04092. Both active/reactive power losses were reduced to 8.621 kW and 7.445 kVAR, respectively. The reductions in active and reactive power losses were 96.16 % and 92.7 %, respectively. The bus voltages minimum and maximum values improved to 1.033656 and 1.041507 pu, respectively.

4.2. IMPACT OF THE PROPOSED METHODOLOGY ON VOLTAGE PROFILE

Fig. 5 illustrates the IEEE 69-bus network voltage profile for all scenarios. In the initial form, some buses violated the voltage borders. After applying the proposed methodology, the bus's voltage was enhanced to be under the limitations for all scenarios. These limitations mean that the voltage for each bus of the distribution network must be between 0.95 p.u and 1.05 p.u, as mentioned in Equation 13. The best scenario was Scenario 4, where all the bus voltages closed to one.

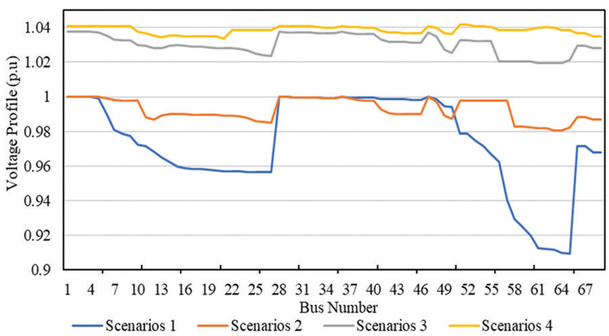

Fig. 5. IEEE 69-bus network of all scenario's voltage profile

4.3. ANALYSIS OF FA'S OVERALL PERFORMANCE

The presented methodology code was run one hundred times. Each time, a local solution was saved. The minimum value between these local solutions is called the global solution, which represents the best solution. The best solution presented the optimal configuration, optimal DG sizing and location, optimal capacitor sizing and location, and optimal TCA. The convergence of the global solutions for all scenarios was drawn and is compared in Fig. 6. From the convergence performances analyzed, Scenario 4 obtained the best fitness.

Fig. 7 illustrates the robustness test of the proposed methodology. The FA was strongly robust since all fitness values were close together for all runs in Scenario 4. The robustness of the FA is also evaluated in Table 4 by calculating the standard deviation for all scenarios. The minimum, maximum, and average values are also calculated for all scenarios. Scenario 4 achieved the best values, obtaining the best standard deviation of 0.010504. The value of standard deviation should be close to zero for the robustness method. That means that the FA was effective and robust in determining the optimal solutions for a complex problem.

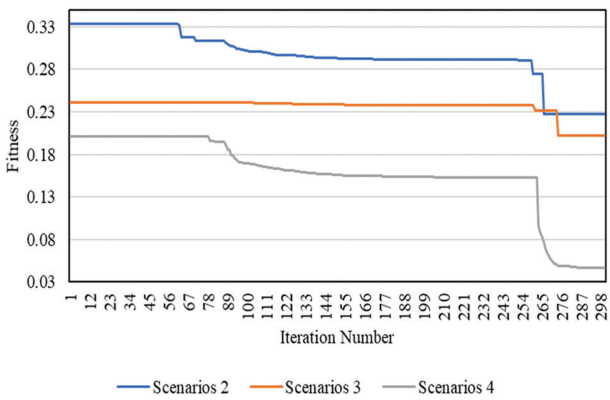

Fig. 6. Convergence curve of all scenarios

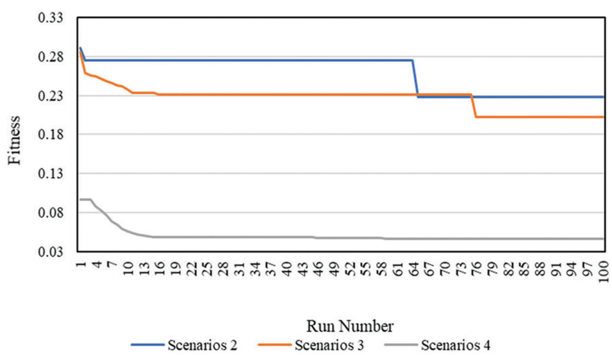

Fig. 7. Robustness curve of all scenarios

Table 4. Robustness test statistical analysis for all scenarios

Scenario	Min value	Max value	Average value	Standard deviation
Scenario 2	0.22785	0.291004	0.258075	0.022726
Scenario 3	0.20233	0.285469	0.226285	0.01566
Scenario 4	0.046091	0.096183	0.050388	0.010504
Scenario 5	0.22785	0.291004	0.258075	0.022726

Table 5 outlines our results compared with those obtained in other published works. From the results, it can be seen that the power loss obtained from the proposed method using the FA and AHP is 39.16 kW, while when using other methods, the power loss obtained is greater than 39.16 kW. Thus, the reduction in the power loss using the FA is 82.56 %, meaning that the maximum value was achieving using this method compared to others. The proposed methodology using the FA and AHP was the best as this obtained minimum power loss and maximum loss reduction.

Table 5. Results comparative

Scenario 2	Open switch	DG outputs (MW)	Weaker Bus voltage (pu)	Power loss (kW)	Loss reduction (%)
GA [43]	10, 55, 45, 15, 62	2.02920	0.97270	46.500	73.380
RGA [43]	10, 55, 14, 16, 62	2.06540	0.97420	44.230	80.320
HSA [43]	69, 58, 13, 17, 61	1.87180	0.97360	40.300	82.080
FWA [44]	69, 70, 13, 55, 63	1.8182	0.9796	39.25	82.55
MPSO [8]	14-58-61-69-70	2.2736	0.98994	42.2	81.1
ISCA [45]	12, 9, 57, 63, 69	1.8731	-	39.73	82.34
The proposed method by FA	13, 12, 62, 10, 57	2.4012	0.98035	39.16	82.56

5. CONCLUSIONS

Different methods like network reconfiguration, distributed generation location and sizing, tap changer adjustment, and capacitor location and sizing play an important role in distribution networks because they reduce power losses and improve voltage profile. This paper proposed a new methodology that combined the FA and AHP to tackle these methods simultaneously. The proposed methodology can perform optimal network reconfiguration, distributed location and sizing, tap changer adjustment, and capacitor location and sizing simultaneously. Several scenarios were performed on the IEEE 69-bus network. In this work, Scenario 4 showed higher active and reactive power loss reduction when all methods were considered simultaneously compared to the other scenarios. Furthermore, the voltage profile index was improved in all scenarios, especially in Scenario 4. Moreover, the results proved that the FA is strongly robust and accurate when finding global solutions for complicated problems and comparing them to other published works. Finally, we compared part of our results to those obtained in other reported works. On the whole, our results showed that we obtained better active power loss than other reported studies have. Future research could focus on the switching sequence order that changes the original network form to the optimal network form. Furthermore, dynamic load and renewable energy could be integrated into the distribution network.

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