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# Loss Minimization and Voltage Enhancement Through DGs Sizing and Locations Considering TCA and Network Reconfiguration during Load-Variation

# تقليل الخسارة وتعزيز الجهد من خلال تحديد الموقع والحجم الأمثل لمولد التوزيع بالتزامن مع تعديل صنبور المحول وإعادة تشكيل الشبكة اثناء تغيير الاحمال

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**Abstract:** Distribution Network Reconfiguration (DNR) is the most popular technique used to minimize power loss. However, applying the reconfiguration method alone will reduce power loss up to a specific value. Furthermore, Distributed Generation (DG) optimal sizing would also reduce power loss. However, a combined reconfiguration process with DG optimal sizing at an un-optimal location may raise power loss and voltage variation. So, it is important to evolve an efficient optimization method that determines the DG optimal sizing and optimal location and ensures optimal configuration at the same time. This work presents a new methodology that aims to find the best simultaneous solution that encompasses the optimal network reconfiguration and optimal DG Location and Sizing (DG_LS) beside the optimal value of the Tap Changer Alteration (TCA). In addition, the impact of load variation on network reconfiguration is also studied. Power loss reduction and overall voltage profile improvement using the firefly optimization technique are the aims of the presented methodology. Different scenarios were considered to examine the validity of the presented methodology. The output results confirm the validation of the proposed strategy to find the optimal simultaneous system configuration, the optimal generation output and location of units of DG, and the optimal tap changer alteration. In terms of active power and reactive losses, reductions in the test system of 74.53% and 71.26%, respectively, were achieved through scenario 5, evidencing the positive impact of the proposed methodology on distribution networks.

**Keywords**: Distributed Generation Sizing and Location, Distribution Reconfiguration, Tap Changer Alteration, Voltage Profile, Power Loss.

**المستخلص**: تعد إعادة تشكيل الشبكة هي التقنية الأكثر شيوعًا المستخدمة لتقليل فقدان الطاقة. ومع ذلك، فإن تطبيق طريقة إعادة التشكيل وحدها سوف يقلل من فقدان الطاقة إلى قيمة محددة. علاوة على ذلك، يمكن أن يؤدي دمج مولد التوزيع أيضًا إلى تقليل فقد الطاقة. ومع ذلك، فإن عملية إعادة تشكيل الشبكة المدمجة مع المولدات

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بطريقة غير مثالية قد تؤدي إلى زيادة فقدان الطاقة وتغير الجهد. لذلك، من المهم تطوير طريقة تحسين فعالة تحدد كميات التوليد المثلى للمولدات وتضمن التشكيل الأمثل للشبكة بشكل متزامن. يقدم هذا العمل منهجية جديدة تهدف إلى إيجاد الحل الأمثل المتزامن الذي يشمل إعادة التشكيل الأمثل للشبكة وتحديد مواقع وكميات التوليد المثلى بالإضافة لتحديد قيمة صنبور المحول المثلى. بالإضافة إلى ذلك، تمت دراسة تأثير اختلاف الأحمال على إعادة تشكيل الشبكة. إن تقليل فقدان الطاقة وتحسين منحنى الجهد الكهربائي باستخدام تقنية تحسين اليراع هي أهداف الطريقة المقترحة. تم النظر في سيناريوهات مختلفة لأنظمة الشبكات لفحص صلاحية الطريقة المقدمة. تؤكد نتائج المخرجات التحقق من صحة الإستراتيجية المقدمة للعثور على التشكيل الأمثل للشبكة وتحديد مواقع ومخرجات المولدات المثلى بالإضافة لتحديد قيمة صنبور المحول المثلى بشكل متزامن. من حيث الطاقة الفعالة وغير الفعالة، تم تحقيق تخفيضات في نظام الاختبار بنسبة 74.53% و71.26% على التوالي، من خلال السيناريو 5، مما يدل على التأثير الإيجابي للمنهجية المقترحة على شبكات التوزيع.

**الكلمات المفتاحية**: موقع وحجم المولد، إعادة تشكيل الشبكة، تعديل صنبور المحول، معامل الجهد، فقدان الطاقة.

## 1. INTRODUCTION:

Nowadays distribution network power loss is a common problem due to the increased demand for electricity. That caused an increase in the operating cost related to the companies of electrical distribution and decreased the voltage profile of the network (Andervazh et al., 2013; Montoya et al., 2020; Riaño et al., 2021; Tang, 2020). Therefore, various strategies are suggested by researchers to solve network problems (Badran et al., 2017a).

Power losses in the distribution network (DN) are the most important issue in the distribution system (DS). The reconfiguration process is one of the most efficient processes used to reduce the distribution power loss to increase the reliability indices (Nguyen & Truong, 2015). Reconfiguration is the process of changing the topography structure of the network by alternating the state of the tie and sectionalizing switches. That aims to reduce real power loss and relieve overload in the network. Therefore, power loss reduction is the most important goal of all researchers (Helmi et al., 2021; Uniyal & Sarangi, 2021). In (Abdelaziz, 2017), the authors presented a new method to solve the network reconfiguration optimization problem based on a Genetic algorithm (GA). This algorithm was used to deal with the non-linear constrained and the complex combination of the reconfiguration problem. The presented method suggested a variable population size of GA, unlike many previous works that fixed the GA population size throughout the evolution of the process search. The results proved that the optimal solution becomes more efficient compared with the standard GA if the population size varies with the status of the GA search. While in (Pegado et al., 2019), the authors presented a new IS-BPSO to solve the DNR problem. That proposed a new sigmoid function to improve the convergence of the results and control the particles' rate of change. The proposed method was applied on 33-bus and 94-node test systems that aimed to minimize power loss. The obtained output results were shown guaranteed and efficient in finding the optimal solution.

Moreover, to improve voltage profile distributed generation units are integrated into the network system (Avchat & Mhetre, 2020; Sedghi et al., 2013). The DG can supply the electric power to the load when the demand is high. Also, DG is important for both consumers and utilities since it leads to improving the system's reliability and stability (HA et al., 2017; Karunarathne et al., 2021). In (Moradi & Abedini, 2012), a hybrid GA and PSO algorithm was proposed to find the optimal DG sizing and location. That aimed to reduce the total power losses and improve the voltage stability and the voltage regulation during the system operation and under the system security constraints. The IEEE 33 system was used to demonstrate the effectiveness of the presented method. The results were encouraging. While in (Mohandas et al., 2015), the authors modify an effective methodology based on the multi-objective index to modify the stability of the voltage for the radial network. A Chaotic Artificial Bee Colony (CABC) algorithm was used to solve the DG problems under operations constraints based on the weighting coefficients of the different technical issues. Different load models such as residential, industrial, and commercial were considered and applied on 38 and 69-node systems to validate the efficiency of the presented algorithm.

Furthermore, the performance of the distribution network was improved by applying the techniques of network reconfiguration and DG size together (Badran & Jallad, 2023b, 2023c). In (Rao et al., 2012)The authors proposed a new methodology that simultaneously solves the DG sizing, locations, and network reconfiguration. The aim was to reduce distribution system power losses and improve the bus's voltage profile. The HSA was used to solve the problem. Different scenarios were applied on 33 and 69 bus distribution systems with load variation to demonstrate the presented method's performance. The obtained results were effective. While in (Badran et al., 2017b; Badran, Mokhlis, Mekhilef, Dahalan, et al., 2018) the authors applied the previous technique using dynamic load. Moreover, in (Imran et al., 2014) a new method based on the Fireworks Algorithm (FWA) was suggested to solve reconfiguration and DG location problems that aimed to reduce power loss and improve the stability index. The Voltage Stability Index (VSI) was used to determine the optimal locations of DGs on different test systems with different load levels. Different scenarios were presented to assess the effectiveness of the suggested method. The output simulated results demonstrated the efficiency of the suggested methodology. Furthermore, in (Badran, Mokhlis, Mekhilef, & Dahalan, 2018), the authors proposed an effective methodology to reduce the overall network power loss, minimize the DG output, and improve the index of the voltage profile. The presented method was solving simultaneously the network reconfiguration problem with the presence of DG output. Different metaheuristic algorithms were used to demonstrate the presented method on a radial distribution system. The obtained outputs were successfully proved by the presented method. In (Al-Qasem, 2012; Badran & Jallad, 2014), the authors presented a photovoltaic system (PV) with storage units to feed a standalone system.

Different from the previous works on network reconfiguration, the major contribution of this paper is to find the optimal simultaneous solution that combines the optimal distribution configuration with optimal DG_LS considering TCA for load variations. The major aims of this work are to reduce the active and reactive power losses and to enhance the overall voltage profile. Other different published works were compared to the obtained results. The content of this work is ordered as follows: Section 2 presents the objective fitness and limitations, Section 3 provides the proposed strategy, Section 4 gives the simulation results and discussion, and Section 5 explains the conclusions.

## 2. OBJECTIVE FITNESS AND LIMITATIONS:

The proposed methodology aims to obtain the optimal DNR simultaneously with DG_LS including TCA to minimize the power losses and minimize the index of the voltage profile at the same time. The fitness function is (Badran, 2023):

$$F = (P_{loss} + IVD) \quad (1)$$

The power loss is formulated by:

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

where, $P_{loss}$ is the active power loss; M is the branch number; $R_N$ is the resistance of the branch N; $I_N$: is the current.

The Index of Voltage Profile definition is as follows:

$$IVD = \max_{i=2}^{n} \frac{(|V_1| - |V_i|)}{|V_1|} \quad (3)$$

where, $V_1$: is the rated voltage value of the bus 1; $V_i$: is the bus voltage.

The presented method must fulfill the following constraints:

The DG output Capacity:

$$P_i^{min} \leq P_{DG,i} \leq P_i^{max} \quad (4)$$

where, $P_i^{max}$ and $P_i^{min}$: are the size limitations of the DG.

Power Injection:

$$\sum_{i=1}^{k} P_{DG,i} < (P_{Load} + P_{loss}) \quad (5)$$

where, k is the DG number; $P_{Load}$ is the load active power.

Balance power:

$$\sum_{i=1}^{k} P_{DG,i} + P_{Substation} = P_{Load} + P_{loss} \quad (6)$$

where $P_{Substation}$ the main substation active power; $P_{Load}$ is the active power load. The power supply must be equal to power generation.

Voltage Magnitude:

$$V_{min} \leq V_{bus} \leq V_{max} \quad (7)$$

$0.95\ p.u \leq V_{bus} \leq 1.05\ p.u$ (Rahim et al., 2019).

Configuration Form:

Any system must be in radial form. Therefore, a MATLAB code is used:

$$\mathrm{TF} = \mathrm{graphissap\_ntree(G)} \tag{8}$$

$$\mathrm{TF} = \begin{Bmatrix} 1 & \mathrm{radial} \\ 0 & \mathrm{not\_radial} \end{Bmatrix} \tag{9}$$

where, G: is the system.

Load Isolation:

All buses must be connected and receive power from the sources.

**Tap changer position alteration:**

In this work, the position of the tap changer is adjusted to 17 positions (Azimi & Esmaeili, 2013), which changes the voltage value between (−5 to +5) %. This is equivalent to 0.95 p.u and 1.05 p.u for both the lower voltage and the upper voltage, respectively as shown in Table (1).

*Table 1 : Tap Changer position vs Voltage Value*

| TCA | The corresponding voltage value in p.u |
|---|---|
| -8 | 0.95000 |
| -7 | 0.95625 |
| -6 | 0.96250 |
| -5 | 0.96875 |
| -4 | 0.97500 |
| -3 | 0.98125 |
| -2 | 0.98750 |
| -1 | 0.99375 |
| 0 | 1.00000 |
| 1 | 1.00625 |
| 2 | 1.01250 |
| 3 | 1.01875 |
| 4 | 1.02500 |
| 5 | 1.03125 |
| 6 | 1.03750 |
| 7 | 1.04375 |
| 8 | 1.05000 |

## 3. PROPOSED STRATEGY:

The optimized process is to reconfiguration the network simultaneously with DG sizing and location including tap changer alteration using Firefly (FA). FA is the meta-heuristic technique that is used in this paper (Badran & Jallad, 2023a). According to the proposed method and for more robust results, 5 scenarios are presented to study the superiority of the methodology which are:

Scenario 1: Initial Distribution Network;

Scenario 2: Distribution Network Reconfiguration (DNR);

Scenario 3: Distributed Generation Sizing (DG_S);

Scenario 4: Distributed Generation Location and Sizing (DG_LS);

Scenario 5: Tap Changer Alteration (TCA).

Scenario 1 represents the initial case (Base case). Scenario 2 represents the reconfiguration process case. Scenario 3 represents the reconfiguration simultaneously with DG sizing for fixed DG location cases. Scenario 4 represents the reconfiguration simultaneously with DG sizing and location case.
Scenario 5 represents the reconfiguration simultaneous with DG sizing and location and tap changer alternation.

All scenarios are programmed using MATLAB software through a PC with an 8-GB-RAM and a 3.07 GHz CPU. For the implementation of the FA technique, the size of the population is set to be one hundred populations (POP). Number of the iterations is set to be three hundred iterations (ITER).

Figure (1) presents the flowchart of the proposed methodology using FA for scenario 5. FA is a meta-heuristic approach (Gandomi et al., 2011; XS, 2010). The steps for this method are as follows:

1. Set the POP_size and iterations NO (ITER) of the FA.

2. Determine the line's reactance and resistance values, bus voltages at the initial time, and initial TCA positions.

3. Create matrix X that presents the random initial FA population. It must fulfill all limitations.

$$X = \begin{bmatrix} S_{11} & S_{12} \cdots S_{1n} & DG_{S11} & DG_{S12} \cdots DG_{S1k} & DG_{L11} & DG_{L12} \cdots DG_{L1q} & T_{P1} \\ S_{21} & S_{22} \cdots S_{2n} & DG_{S21} & DG_{S22} \cdots DG_{S2k} & DG_{L21} & DG_{L22} \cdots DG_{L2q} & T_{P2} \\ \vdots & \vdots \cdots \vdots & \vdots & \vdots \cdots \vdots & \vdots & \vdots \cdots \vdots & \vdots \\ S_{m1} & S_{m2} \cdots S_{mn} & DG_{Sm1} & DG_{Sm2} \cdots DG_{Smk} & DG_{Lm1} & DG_{Lm2} \cdots DG_{Lmq} & T_{Pm} \end{bmatrix} \quad (10)$$

where S is the tie switch number; $DG_S$ is the DG size and $DG_L$ is the location of the DG; $T_P$ is the TCA position; n: is the open switches number; $k = q$ and represent the DGs number; m is the POP_size.

4. Run the load flow code which is based on the Newton–Raphson method. Then evaluate the total $P_{loss}$ and $Q_{loss}$ besides the minimum value of the bus's voltages.

5. Evaluate the value of the fitness of the matrix X for each population based on equation number (1).

6. Sort the populations based on fitness and keep the best value that achieved the best minimum value.

$$\text{L-Int, Index} = \text{Sort}(X)$$
$$\text{Light}_{best} = L(1) \quad (11)$$

7. Update the element of the matrix X related to the FA method without violating the limitations based on the following equations:

$$\beta(r) = \beta_0 e^{-\gamma r^2} \quad (12)$$

where, r is the two FA distances; $\beta_0$ is the attractiveness value at $r = 0$ ; $\gamma$ is the coefficient value of the light absorption.

$$r_{lj} = \|x_l - x_j\| = \sqrt{\sum_{k=1}^{d}(x_{l,k} - x_{j,k})^2} \quad (13)$$

where, $r_{lj}$ is the l and j distance of the firefly; d is the parameter number to be optimized; $x_{l,k}$ and $x_{j,k}$ represent $k_{th}$ cartesian coordinate components $x_l$ and $x_j$ of FA l and j, respectively.

$$x_{l,k}(new) = x_{l,k}(old) + \beta_0 e^{-\gamma r_{lj}^2}(x_{j,k} - x_{l,k}) + \alpha(rand - 0.5) \quad (14)$$

where the second term is attraction affected (when $\gamma = 1$); while the third term proposes $\alpha$ random parameter.

8. Repeating the previous process to end the iteration numbers from step 4 to step 8.

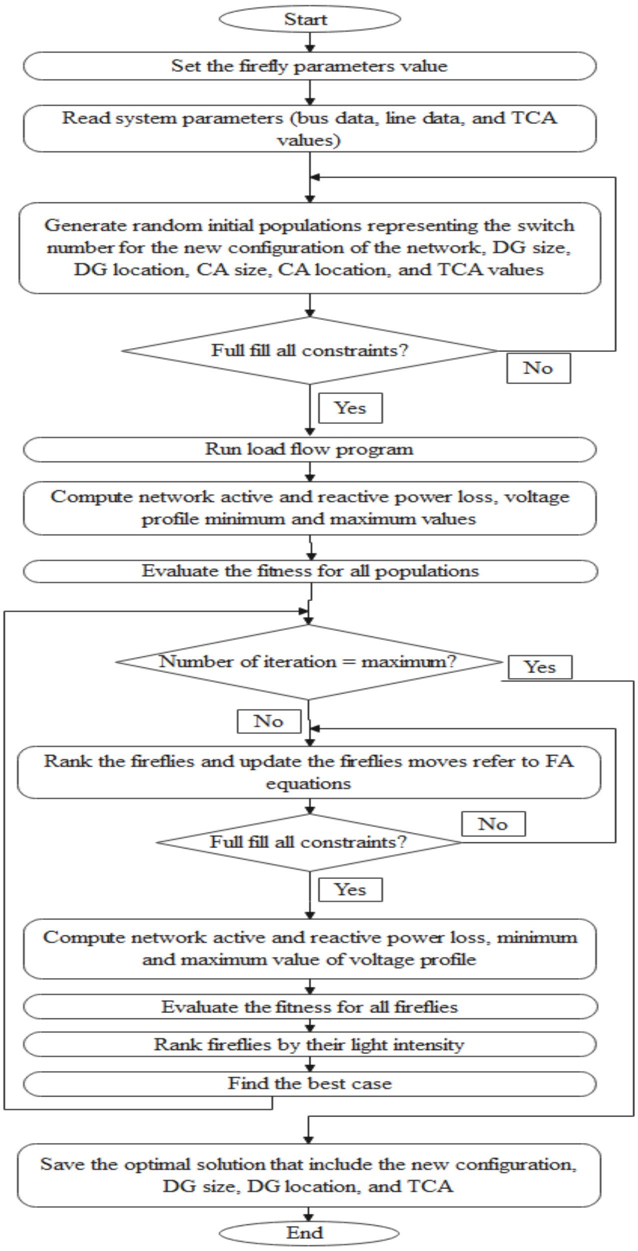


Figure 1 : Reconfiguration Simultaneously with DG Output Sizing and Location Including Tap Changer Alteration Flowchart.

9. Stop the run process and then obtain the optimum fitness. It consists of the new configuration, DG location and output sizing, and TCA position. That obtains the best IVD and the minimum $P_{loss}$ and minimum $Q_{loss}$.

10. Rerun the proposed approach 100 times to check the robustness of the presented strategy.

## 4. SIMULATION RESULTS AND DISCUSSION:

This section presents the results of the proposed method. The presented methodology has been applied to an IEEE-33 bus network distribution system shown below in Figure (2). The data of the test network is proposed in (Badran et al., 2020) and presented in Table (2). The line and bus data are given in (Baran & Wu, 1989; Ola Subhi, 2018). The Optimal results were obtained for the open switch, DG location, DG output as a real power, and tap changer alteration value. For the initial case, the value of tap changer alteration value is assumed to be 1p.u. Opened switches, DG location, sizing and the tap changer alteration were determined simultaneously.

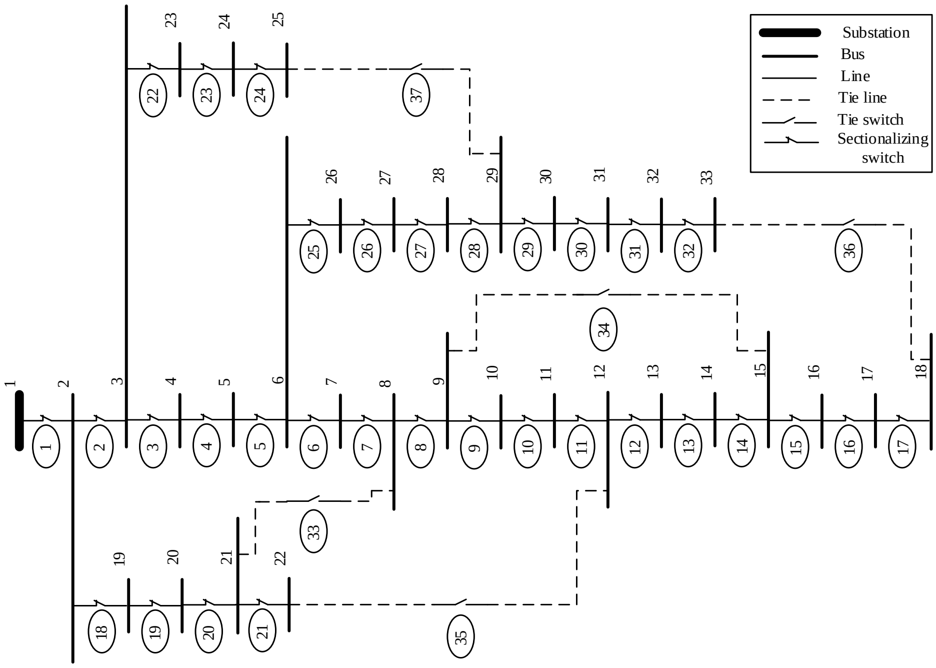


Figure 2: Distribution Network System.

**Network Reconfiguration Simultaneously with DG sizing and the location including tap changer alteration**

This section focuses on improving the bus's voltages and reducing power loss via simultaneous reconfiguration and DG sizing and location including the tap changer. Table (3) illustrates the output results obtained by using FA and compared to other presented scenarios. It's seen that scenario 5 provides a better result according to other scenarios. For the initial case, switches number 33 to 37 are opened while other switches are closed. The optimal configuration using FA for scenario 2 is 7, 10, 14, 28, and 32. Scenario 3 is 7, 10, 13, 28, and 32. Scenario 4 is 7, 14, 27, 30, and 35. Scenario 5 is 7, 8, 10, 28, and 36. The minimum fitness is 1.1135, 0.781, 0.411, 0.338, and 0.257 for scenarios 1 to 5, respectively. The Ploss and Qloss are minimized to 140.7kW and 105.5 kVAR, respectively for scenario 2 compared to the initial case. The Ploss and Qloss reduction is 30.55 % and 21.85 %, respectively. For scenario 3, the Ploss and Qloss are minimized to 72.36 kW and 55.2 kVAR, respectively. The Ploss and Qloss reduction is

64.28% and 59.11%, respectively. For scenario 4, the Ploss and Qloss are minimized to 57.637kW and 44.6kVAR, respectively. The Ploss and Qloss reduction is 71.55% and 66.96%, respectively. For scenario 5, the Ploss and Qloss are minimized to 51.596kW and 38.8kVAR, respectively. The Ploss and Qloss reduction is 74.53% and 71.26%, respectively. The Min and Max bus voltages are improved to 0.941 p.u and 1 p.u, respectively scenario 2 compared to the initial case. For scenarios 3 and 4, the Min and Max bus voltages are improved to 0.975 p.u and 1 p.u, respectively. For scenario 5, the Min and Max bus voltages are improved to **1.028** p.u and 1.05 p.u, respectively.

*Table 2: Distribution Network System Features*

| Item | Vale |
|---|---|
| Network switches number | 37 |
| Number of sectionalizing switches | 32 |
| Normally closed switches | 1, 2, 3, ... , 32 |
| Number of tie switches | 5 |
| Normally open switches | 33, 34,35, 36, and 37 |
| Load Active Power P | 3715 kW |
| Load Reactive Power Q | 2300 kVAR |
| System's voltage | 12.66 kV |
| Base value of the Apparent power | 100 MVA |
| Power loss of the initial form | 202.677 kW |
| Lowest value of voltage profile | 0.913 pu |

*Table 3: Proposed Method Scenarios Results*

| Scenario | Scenarios **1** | Scenarios **2** | Scenarios **3** | Scenarios **4** | Scenarios **5** |
|---|---|---|---|---|---|
| **Tie switch (normally open switch)** | 33, 34, 35, 36, 37 | 7, 10, 14, 28, 32 | 7, 10, 13, 28, 32 | 7, 14, 27, 30, 35 | **7, 8, 10, 28, 36** |
| **DG_L (DG_S (MW))** | --- | --- | 31 (0.676)<br>32 (0.516)<br>33 (0.6330 | 32 (0.667)<br>29 (1.1510<br>9 (0.8340 | **15 (0.778)**<br>**6 (0.694)**<br>**30 (1.409)** |
| **TCA** | --- | --- | --- | --- | **1.05** |
| **Fitness** | 1.1135 | 0.781 | 0.411 | 0.338 | **0.257** |
| **Ploss (kW)** | 202.6 | 140.7 | 72.36 | 57.637 | **51.596** |
| **Qloss (kVAR)** | 135 | 105.5 | 55.2 | 44.6 | **38.8** |
| **Ploss Reduction (%)** | --- | 30.55 | 64.28 | 71.55 | **74.53** |
| **Qloss Reduction (%)** | --- | 21.85 | 59.11 | 66.96 | **71.26** |
| **Bus-voltage (p.u) min-max** | 0.913–1 | 0.941-1 | 0.975-1 | 0.975-1 | **1.028-1.05** |

The voltage profiles for all scenarios using FA are shown in Figure (3). The magnitude of all busses of each scenario is improved compared to the initial case. The best voltage profile is related to scenario number 5 where all bus's voltages are close to unity.

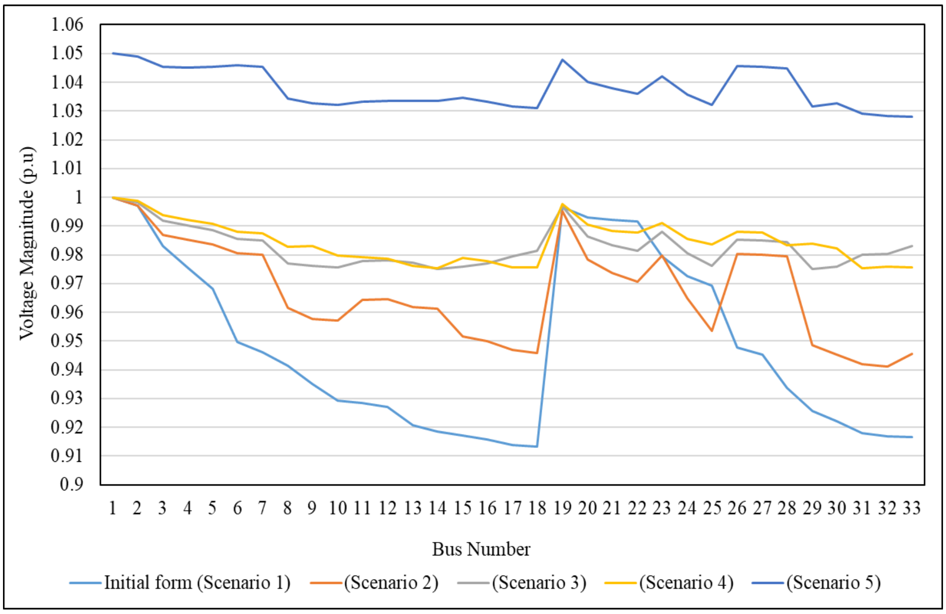


*Figure 3: Distribution Voltage Profile for All Scenarios.*

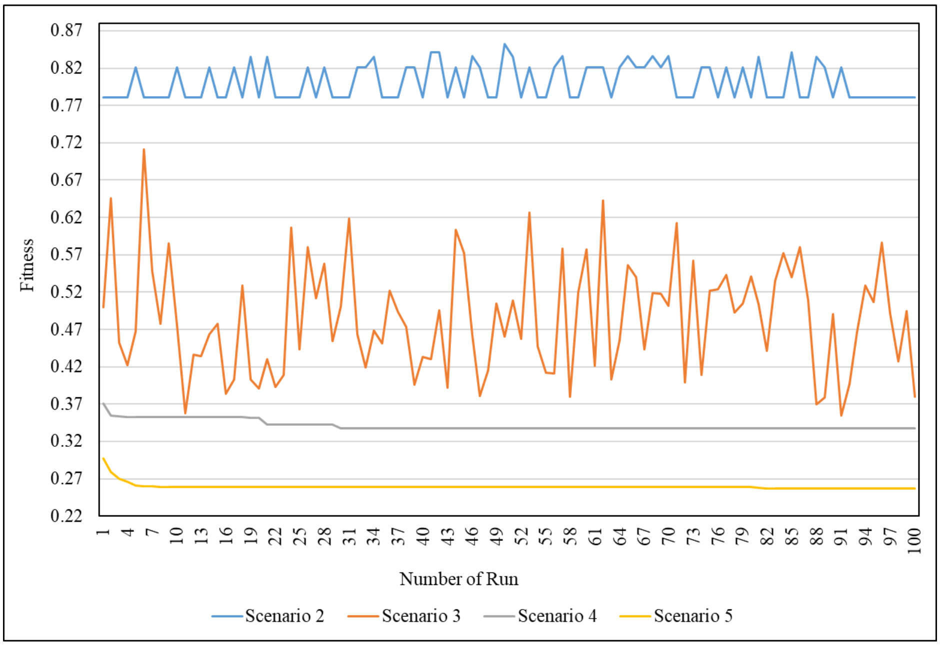


*Figure 4: Robustness Test Comparison of the Different Scenarios.*

Table 4: Statistical Analysis of Robustness Test for All Scenarios

| Scenario | Min | Max | Average | Standard deviation |
|---|---|---|---|---|
| 2 | 0.781 | 0.852 | 0.800 | 0.0236 |
| 3 | 0.355 | 0.711 | 0.485 | 0.0744 |
| 4 | 0.3382 | 0.371 | 0.342 | 0.0066 |
| 5 | 0.257 | 0.298 | 0.259 | 0.0047 |

Figure (5) shows the convergence performance of the FA after running the code 100 times. The best run is the global optimal solution. The convergence performance of the global values was illustrated and compared for all scenarios in Figure 5. Scenario 5 obtained the minimum value of the fitness.

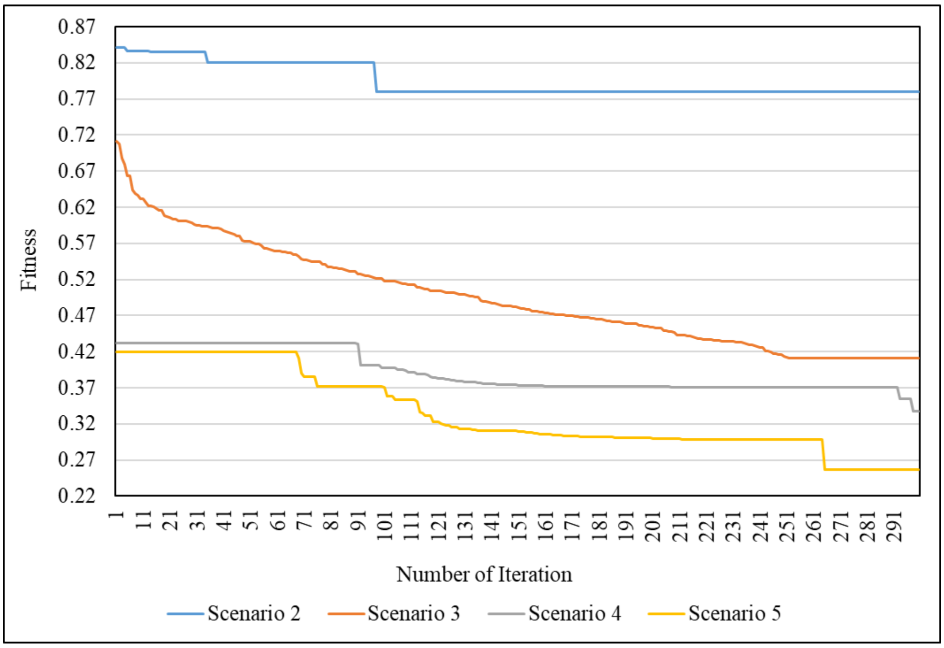

Figure 5: Convergence Performance Comparison of The Different Scenarios.

The performance of the presented methodology was compared with other published results as illustrated in Table (5). Scenario 4 was taken for the comparison since there are many published works about the same case using different algorithms. The presented methodology based on FA provides results better than other algorithms.

Moreover, to prove the superiority of the presented methodology, the performance of the proposed FA tested on the best scenario (scenario 5) under different load levels is presented in Table (6). As mentioned previously scenario 5 solves the simultaneous DNR and DG_LS including the TCA problem. The different load levels are classified as follows:

1 .Light Load Condition that assumes the load is 50% of the normal load .
2 .Normal Load Condition without any change of the normal load .
3 .Heavy Load Condition that increases the load to 160% of the normal load.

The results in Table (6) present some points which are:
1 .The active power loss for the initial case are 47.052 kW, 202.6 kW, and 575.13 kW for light, normal, and heavy loads respectively .
2 .The reactive power loss for the initial case is 31.343 kVAR, 135 kVAR, and 384.17 kVAR for light, normal, and heavy load respectively .
3 .The active power loss after optimization (Scenario 5: network reconfiguration simultaneously with DG sizing and location including tap changer alternation) are 13.222 kW, 51.596 kW, and 57.9 kW for light, normal, and heavy load respectively. That means the active power reductions are 71.899%, 74.53%, and 89.93% for light, normal, and heavy load respectively .

*Table 5: Simulation Result Comparison*

| Scenario 4 | Open switch | DG output (kW) | Minimum bus voltage (pu) | Power loss (kW) | Loss reduction (%) |
|---|---|---|---|---|---|
| **GA (Rao et al., 2012)** | 7, 34, 28, 32, 10 | 1963.3 | 0.9766 | 75.13 | 62.92 |
| **RGA (Rao et al., 2012)** | 7, 32, 12, 27, 9 | 1774 | 0.9691 | 74.32 | 63.33 |
| **HSA (Rao et al., 2012)** | 7, 32, 14, 28, 10 | 1668.4 | 0.97 | 73.05 | 63.95 |
| **FWA (Imran et al., 2014)** | 7, 32, 14, 28, 11 | 1684.1 | 0.9713 | 67.11 | 66.89 |
| **EP (Badran, Mokhlis, Mekhilef, & Dahalan, 2018)** | 7, 8, 9, 28, 32 | 1963.8 | 0.971 | 73.971 | 63.49 |
| **PSO (Badran, Mokhlis, Mekhilef, & Dahalan, 2018)** | 7, 10, 13, 28, 32 | 1766 | 0.9738 | 72.421 | 64.30 |
| **GSA (Badran, Mokhlis, Mekhilef, & Dahalan, 2018)** | 7, 9, 13, 28, 32 | 1745 | 0.9742 | 72.425 | 64.25 |
| **FA (Badran, Mokhlis, Mekhilef, & Dahalan, 2018)** | 7, 10, 13, 28, 32 | 1825 | 0.9750 | 72.361 | 64.28 |
| **PSO (Haider et al., 2021)** | 7, 9, 14, 28, 32 | 2954.1 | 0.9611 | 64.91 | 67.96 |
| **MPSO (Essallah & Khedher, 2020)** | 7, 9, 14, 32, 37 | 1092.3 | 0.9764 | 62.4 | 68.32 |
| **ISCA (Raut & Mishra, 2020)** | 7, 9, 14, 28, 31 | 1691.2 | - | 66.81 | 67.03 |
| **Proposed method by FA** | **7, 35, 27, 30, 14** | **2652** | **0.975** | **57.637** | **71.55** |

4 .The reactive power loss after optimization (Scenario 5: network reconfiguration simultaneously with DG sizing and location including tap changer alternation) are 10.151 kVAR, 38.8 kVAR, and 54.689 kVAR for light, normal, and heavy load respectively. That means the reactive power reductions are 67.613%, 71.26%, and 85.76% for light, normal, and heavy load respectively.

7. The minimum and maximum values of the voltage profile are under constraints and close to unity.

*Table 6: Performance Analysis Under Different Load Levels*

| Cases / Parameters | Load level | | |
|---|---|---|---|
| | **Light (0.5)** | **Nominal (1)** | **Heavy (1.6)** |
| **P (kW)** | 1857.5 | 3715 | 5944 |
| **Q (kVAR)** | 1150 | 2300 | 3680 |
| **Initial $P_{loss}$(kW)** | 47.052 | 202.6 | 575.13 |
| **Initial $Q_{loss}$ (kVAR)** | 31.343 | 135 | 384.17 |
| **Tie switch** | 5, 13, 26, 9, 17 | 7, 8, 10, 28, 36 | 7, 13, 24, 28, 35 |
| **DG_L (DG _S (MW))** | 30 (0.600) | 15 (0.778) | 7 (0.6930 |
| | 8 (0.584) | 6 (0.694) | 17 (0.670) |
| | 24 (0.467) | 30 (1.409) | 3 (0.501) |
| **TCA** | 1.0499 | 1.05 | 1.0484 |
| **Fitness F** | 0.0573 | 0.257 | 0.3014 |
| **$P_{loss}$ (kW)** | 13.222 | 51.596 | 57.9 |
| **$Q_{loss}$ (kVAR)** | 10.151 | 38.8 | 54.689 |
| **$P_{loss}$ Reduction (%)** | 71.899 | 74.53 | 89.93 |
| **$Q_{loss}$ Reduction (%)** | 67.613 | 71.26 | 85.76 |
| **Min Bus_Voltage** | 1.0382 | 1.028 | 1.014 |
| **Max Bus_Voltage** | 1.05 | 1.05 | 1.0484 |

## 5. CONCLUSION:

This paper presented a new method to obtain the best solution for the reconfiguration simultaneously with DG sizing and location with the presence of tap changer alteration for load variation. The proposed methodology aimed to find the best index of voltage profile and reduce the active and reactive power losses of the distribution system. Firefly was the optimization technique used to obtain the minimum fitness value. The validity of the presented methodology has been applied to the 33-bus distribution network. The presented method is effective in finding the best solution that combines the optimal DNR with optimal DG_ LS and at the same time with the optimal tap changer alteration for different loads. The obtained results were compared with published work and achieved the best results. The compared results include active and reactive power losses and voltage profiles. Also, the obtained results illustrate that the performance of FA is better than other methods proposed in another published research.

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