Optimal network reconfiguration for power loss minimization and voltage profile enhancement in distribution systems

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ABSTRACT

This paper presents an optimal method for optimizing network reconfiguration (NR) problems in a power distribution system (PDS) for the purpose of power loss reduction and voltage profile (VP) improvement. Furthermore, a modified algorithm was presented to address this problem in order to provide a more efficient PDS. Various works which used NR to improve VP and reduce power loss were discussed and summarized in detail. In particular, a modified Selective particle swarm optimization (SPSO) method was used for NR in existing networks considering different loading conditions. The main objective of this study is to minimize real power losses and enhance VP of a distribution system using the proposed SPSO method. The SPSO method was programmed in MATLAB R2016b software and tested using IEEE 33-bus radial distribution system (RDS). The obtained test results show that the real power was enhanced by 99.341%, 97.289%, and 95.389% for the light, normal, and heavy load conditions, respectively. Also, the minimum voltage level in the worst case was significantly enhanced from 0.8841 p.u. to 0.9510 p.u. Towards the end, a comparative analysis of the proposed SPSO with existing methods for distribution network reconfiguration (DNR) is presented. The comparative results show that the proposed SPSO was found to be more efficient in reducing voltage deviation (VD) and power losses in the system.

1. Introduction

Configuration of a power distribution system (PDS) is a complex activity which is important for electric power systems planning. Poor configuration leads to increased power losses, poor voltage profile (VP), and low power factor [1]. Network reconfiguration (NR), distributed generation (DG), and optimal capacitor placement are power loss minimization techniques which have been used to solve this problem [2]. Among these techniques, NR is being used more often because of its cost effectiveness [3]. NR is the process of changing the topological arrangement of distribution feeders by varying the open/closed status of sectionalizing and tie switches while observing system constraints. NR techniques have many constraints, namely: upper and lower limits of bus voltage, and upper and lower limits of line current. There are two types of switch conditions in a radial distribution system (RDS). The switches are represented as normally closed (sectionalizing switches) and normally opened (tie switches). The reconfiguration of a distribution system is carried out by turning on/off the network switching conditions [3]. The adjustment of the switches depends on the type of objective function adopted [4]; thus, the need to employ an efficient algorithm to implement an optimal NR having various perspectives such as objective function and constraints. The main objective of NR is to minimize active power losses (APLs) and improve VP in order to improve distribution systems performance [4, 5].

Quite a number of researchers have proposed different methods to solve the distribution network reconfiguration (DNR) problem in the last two decades. Rao et al. [6] introduced the harmony search algorithm (HSA) for NR in a distribution system. Sivanagaraju et al. [7] proposed a plant growth simulation algorithm for NR in a distribution system (DS) for loss reduction and load balancing. In this paper, the NR was achieved by onning and offing specific switches in the system. Sulaima et al. [8] presented an optimal NR for minimizing power loss in a DS using evolutionary particle swarm optimization (EPSO). A comparative study of the proposed EPSO method with conventional particle swarm optimization (PSO) techniques in a selected distribution system was performed. Shuaib et al. [9] presented a NR technique in a RDS by using gravitational search algorithm. The main objective of this paper was to alternate the network topology until power loss was minimized and VP was enhanced. Prasad et al. [10] proposed a genetic algorithm (GA) for NR to solve the problem of load balancing in a DS. NR in a feeder was

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performed by changing the open/closed status of sectionalizing and tie switches with respect to a time-varying load. Shirzadah et al. [11] applied a heuristic method for the reconfiguration of distribution networks (DNs). The objective of the proposed method was to reduce resistive line losses under normal operating conditions. Sedighizadeh et al. [12] modelled three demand response (DR) programs for a NR problem. To improve tractability, the model was formulated as a mixed-integer second-order cone programming (MISOCP) problem in order to minimize operational cost subject to technical and financial constraints. Raposo et al. [13] proposed a Multi-Objective Biased Random-Keys Genetic algorithm for meter allocation to reduce energy loss in an electric distribution system. This method helped to prevent the degradation of the State Estimator Accuracy (SEA) after NR was carried out.

The reviewed papers in [6, 7, 8, 9, 10, 11, 12, 13], show that PDSs are greatly affected by power loss and poor VP [14]. A number of studies have used different approaches to reduce power loss in PDSs such as distributed generation placement [15], optimal capacitor placement [16], and electric distribution network reconfiguration (DNR) [17]. Out of these different approaches, the DNR approach has shown remarkable results for power loss reduction and VP improvement [5, 6, 7, 8, 9, 10, 11, 12, 13]. DNR by placing DGs and capacitor units optimally is very effective in reducing APLs. The most common method used in these papers for DNR is the particle swarm optimization (PSO). A modified PSO called Selective Particle Swarm Optimization (SPSO) was proposed in [14]. SPSO is an AI based approach which selectively locates the optimal location for a particle. It is a stochastic search algorithm influenced by flocking birds or social behavior in fish education. SPSO was derived from the modification of Binary particle swarm optimization (BPSO). The PSO starts with a random-positioned search space population of particles [17]. Each particle is a fitness-value problem-solving alternative. In this type of problem, the algorithm evaluates and optimizes the fitness of these particles. Therefore, each particle's location is changed to its optimal location after each iteration. It uses the concept that teams (particles) progressively work together to achieve the best results (ideal solution in terms of a numerical problem). The main advantage of the PSO is that it has to deal with a few parameters. Some of the PSO algorithm's parameters include particle size, search space size, termination criterion, and acceleration training factors or coefficients.

### 2. Selective particle swarm optimization

Optimization algorithms are suitable for finding the best feasible solution for an optimization problem by minimizing or maximizing a continuous and discrete function with respect to several subjects of equality and inequality constraints. The problems include the optimal selection of capacitor size for reactive power compensation and optimal selection of switching conditions in the DN. Details of the SPSO can be found in [14]. Therefore, this study presents a modification of the SPSO to search a selected space for standard values of capacitor sizing and switching conditions in the loops for which there are minimum power losses in the system. The modified algorithm of the SPSO is given as follows:

Each particle tries to modify its position using the following information [18, 19]:

1. The particle current positions (X)
2. The particle current velocity (V)
3. The distance between the current position and P_best
4. The distance between the current position and P_best

The particle velocity is the sum of the inertia factor, the personal influence, and the social influence in the swarm. In the instance when the velocity of the particle changes, Eq. (1) is used:

$$V_{id}^{t+1} = W * V_{id}^t + C_1 * r_1 * (P_{id}^t - X_{id}) + C_2 * r_2 * (P_{psd}^t - X_{id})$$  \(1\)

To accurately evaluate the modified SPSO, numerous iterations were performed. In the conventional PSO, the search space is a real-valued space, where the search space in the binary PSO is a set of 0's and 1's, but in the SPSO the search space is a set of selected standard values. The i-th particle position at a dimension is selected to update Eq. (2).

$$\text{Sig}(V_{id}^{t+1}) = \text{dn} \left( \frac{1}{1 + e^{V_{id}^{t+1}}} \right)$$  \(2\)

For i = 1, 2… n, and d = 1, 2… m, where

$$V_{id}^{t+1} = \begin{cases} S_{d1} & \text{if } \text{Sig}(V_{id}^{t+1}) < 1 \\ S_{d2} & \text{if } \text{Sig}(V_{id}^{t+1}) < 2 \\ S_{d3} & \text{if } \text{Sig}(V_{id}^{t+1}) < 3 \\ S_{dn} & \text{if } \text{Sig}(V_{id}^{t+1}) < \text{dn} \\ \end{cases}$$  \(3\)

where: S_{d1}, S_{d2}, S_{d3}… S_{dn} are the selected values in the dimension ‘d’. The velocity value (V_{id}^{t+1}) is constrained to some minimum and maximum value [V_{id\text{min}}, V_{id\text{max}}] using Eq. (4).

$$V_{id}^{t+1} = \begin{cases} V_{\text{el\text{max}}} & \text{if } V_{id}^{t+1} > V_{\text{el\text{max}}} \\ V_{id}^{t+1} & \text{if } V_{id}^{t+1} \leq V_{\text{el\text{max}}} \\ V_{\text{el\text{min}}} & \text{if } V_{id}^{t+1} < V_{\text{el\text{min}}} \\ \end{cases}$$  \(4\)

To avoid the oscillation of the particle ‘i’ velocity, at the dimension ‘d’ between the maximum and minimum values, Eq. (5) is used.

$$V_{id}^{t+1} = \begin{cases} \text{rand} * V_{id}^{t+1} & \text{if } V_{id}^{t+1} = V_{id}^t \\ V_{id}^{t+1} & \text{otherwise} \end{cases}$$  \(5\)

In order to represent optimal NR, the design variable in the DS is equal to the number of tie switches in each loop. Therefore, the particle representation of the tie switches is given as

$$X_{\text{Particle}} = [T_{S1}, T_{S2}, T_{S3}...T_{S_{d}}]$$  \(6\)

where: T_{S_i} is the tie switch representation in the DN, and X_{Particle} is the design variable in the algorithm.

Since DNR is subject to a number of imposed constraints, in order to determine the best configuration for a system for loss reduction and VP improvement, our proposed SPSO method uses fewer parameters, and is therefore more suitable for optimization problems as stated in [11]. Since the problem consist of integers and continuous variables, this therefore indicates that the problem is non-trivial, which can therefore be solved using AI or computational techniques [17]. Due to the aforementioned characteristics, a modified SPSO algorithm for optimal NR in a PDS was proposed in this paper.

### 3. Problem formulation for network reconfiguration in the distribution system

If the number of objective functions and their individual weight factors from the sum of the percentages is 100% or 1 p.u., the multi-objective function (MOF) can be represented by a graphical representation containing real power, reactive power loss, and cumulative voltage deviation (CVD).

Figure 1 shows the representation of the MOF having different sub-objects such as real power loss function, reactive power loss function, and CVD function with their respective weight factors. In this case, the MOF is applied for optimal NR. The sum of the individual
objective functions is compress to a general fitness function given by Eq. (7).

\[ ff = \min (f_1, f_2, f_3) \]  
(7)

Therefore,

\[ ff = MOF = \min(W_r * P_L + W_x * Q_L + W_v * CVD) \]  
(8)

where:
- \( P_L \) is the active power loss function;
- \( Q_L \) is the reactive power loss function;
- CVD is the cumulative voltage deviation function;
- \( ff \) is the fitness function; and.
- MOF is the multi-objective function.

The CVD is normally defined as the sum of deviations of the gain value from the desired value at every node on the feeder as given by Eq. (9). The desired value of voltage in the substation is 1.0 p.u.

\[ \text{CVD} = \sum_{i=1}^{n_b} |1 - V_i| \]  
(9)

where:
- \( n_b \) is the total number of nodes;
- CVD is the cumulative voltage deviation; and.
- \( V_i \) is the voltage level in each iteration in the \( i^{th} \) node.

The weight factor contains \( W_r, W_x, \) and \( W_v \) with respect to the real power loss, reactive power losses, and CVD in the MOF, respectively. Generally, the absolute value of the sum of the weight factors is equal to 1 as given by Eq. (10).

\[ |W_r| + |W_x| + |W_v| = 1 \]  
(10)

For problems related to power loss in a DN, the losses caused are in the form real power loss, reactive power losses, and CVD. These losses can be quantified using the weighting factor given by \( W_r, W_x, \) and \( W_v \) to represent real power loss, reactive power loss, and CVD in the MOF, respectively. The MOFs to be minimized can be assigned weighting factors according to their level of significant or importance. Because of this, we have used the weighted sum of the three objective functions as given by Eq. (10) to determine the overall impact and have also assigned the weight of one as a multiple of the other as given by Eq. (8).

3.1. Voltage limit

This constraint is considered to make sure the voltage level of each bus is within predefined limits as given in Eq. (11).

\[ V_{\text{min}} \leq V_i \leq V_{\text{max}} \]  
(11)

where: \( i = 1, 2, 3... n \),

i. \( V_i \) is the voltage at node \( ‘i’ \);

ii. \( V_{\text{min}} \) and \( V_{\text{max}} \) are the minimum and maximum permissible voltages of the bus \( ‘i’ \).

3.2. Reactive power limit

The maximum value of the capacitor bank injects reactive power to the system until the total reactive power load is given by Eq. (12).

\[ Q_{\text{CTotal}} \leq Q_d \]  
(12)

where: \( Q_{\text{CTotal}} \) is the total compensated kVAR in the capacitor banks.

i. \( Q_d \) is the total load kVAR in the demand side.

3.3. Line loading

In the power flow analysis, the apparent power limit is in the acceptable or less than maximum capacity as given by Eq. (13).

\[ S_k \leq S_k^{\text{max}} \]  
(13)

where:
- \( S_k \) is the power flow in ‘k’ line, and.
- \( S_k^{\text{max}} \) is the maximum allowable power flow.

3.4. Load connectivity

Each bus should be connected via a path to the substation.

3.5. Radial structure

The DN has a number of loops; the number of branches in the network must be smaller than the number of nodes by one unit.

4. Implementation of the proposed SPSO method

4.1. Basic network loop in RDS

The single line diagram in Figure 2 has 33-buses, 32-branches, and 5-tie switches. The optimal network topology of the system is achieved by optimal NR with the help of basic network loops found in the system [18]. The DNR problem using the proposed SPSO was implemented using three steps:

i) Specifying the number of dimensions;
ii) Finding the search space for each dimension;
iii) Using SPSO to select the optimal solution from the search spaces.

i) Specifying the number of dimensions

The DN was designed as multi-loop circuit which runs in open loop to assure the network is in the form of a tree. To specify the number of dimensions for the DNR problem, all tie switches were closed. This enabled us obtain the number of loops. It is important to note that the

Figure 1. Multi-objective function representation.
number of dimensions is equal to the number of loops. This is given by Eq. (14).

Therefore, the number of the basic loops is defined as:

\[ N_{\text{loop}} = \frac{n_l}{n} - 1 \]  
(14)

where:
- \( n_l \) is the total number of system lines,
- \( n \) is the sectionalized switches, and
- \( N_{\text{loop}} \) is the number of loops in the test system.

ii. Finding the search space for each dimension

In this section, Figure 2 is used to explain this procedure. Figure 2 is the single line diagram of the DS before reconfiguration.

1. The system shown in Figure 2 has 33-buses, 32-branches, and 5-tie switches.
2. Closing the tie switches will form 5 loops.
3. The branches which do not belong to any loop will not be represented in the search spaces. Therefore, for the optimization algorithm, the test system shown in Figure 2 is reconfigured to give a simplified system as shown in Figure 7.
4. The number of dimensions is equal to the number of loops, so in this case we have five dimensions.
5. The search space for each dimension will be the branches which belong to the loop represented by these dimensions. In this case, the loops and the number of dimensions are: Loop 1: [2 3 4 5 6 7 18 19 20], Loop 2: [8 9 10 11 12 13 14 35], Loop 3: [12 13 14 34], Loop 4: [22 23 24 25 26 27 28 37], Loop 5: [15 16 17 29 30 31 36 32].

iii. Use the SPSO technique to select the optimal solution from the search spaces. This was performed through simulation and several iterations using the proposed SPSO algorithm.

5. Results and discussion

5.1. Base case load flow results

The base case load flow analysis was performed without compensation and the VP of each bus and real power loss in the distribution lines were computed. For the test system, three load levels were considered: \( S_L = 0.5 \) p.u., \( S_N = 1.0 \) p.u., \( S_H = 1.3 \) p.u. The status of the distribution system for the three different load conditions before optimization using the proposed SPSO algorithm is presented in Table 1.

The VP at light load, normal load, and heavy load are shown in Figure 3. The minimum voltage of the system at light load, normal load, heavy load are 0.9585 p.u., 0.9130 p.u., and 0.8841 p.u., respectively. The voltage regulations of the system are 4.17%, 8.70%, and 11.59% with respect to load variations.

5.2. Optimal network reconfiguration

The proposed method is coded in MATLAB and run on an Intel core i5 PC with 2.6 GHz CPU and 8 GB RAM. In the NR process of the selected...
system, a closed switch status is changed to an open switch status. In the initial network configuration, 33, 34, 35, 36, and 37 are tie switches. Further details of when the system is under different load levels, i.e. light load, normal load, and heavy load are shown in Table 2. After simulation and execution of the program with several iterations, the results of the simulations are presented in Table 2.

5.2.1. Light load condition
When the light load condition is assumed, the load level decreases up to 50% of the normal load. The results for this load level are presented in Table 2. The VP with respect to each bus before and after NR are shown in Figure 4. The minimum voltage level before and after reconguration of the network are 0.9585 p.u. and 0.9715 p.u., respectively. The opened switches in the test system within initial network configuration are 33, 34, 35, 36, and 37. After reconguration of the network using the proposed SPSO algorithm, four tie switches are closed, i.e., 33, 35, 36, and 37, while the sectionalizing switches 7, 11, 28, and 32 are opened and the results are presented in Table 2.

5.2.2. Normal load condition
When the normal load condition is assumed, the results of the VP with respect to each bus before and after NR are shown in Figure 5. The minimum voltage level before and after reconguration of the network are 0.9130 p.u. and 0.950 p.u., respectively.

The results show that the real power loss is reduced by 89.90 kW as compared with that of the base case value of 202.40 kW. This indicates that 70.27 kW of real power can be saved as compared to when the existing network topology is used. The percentage reduction is 44.42% as compared with the total power loss at normal load condition. Reconfiguration of the network using SPSO algorithm resulted in the closing of four tie switches, namely: 33, 35, 36, and 37, while the sectionalizing switches were made opened. The opened switches are: 7, 11, 28, and 32 as shown in Figure 7.

5.2.3. Heavy load condition
Similarly, the heavy load condition is assumed independently and the load level is increased to 130% of the normal load level. The worst

![Figure 3. Voltage profile in base case condition for varying loads for 33-bus test system.](image)

| Load level | Parameters | Base network | After optimization |
|------------|------------|--------------|-------------------|
| Light load | Switch to be opened | 33, 34, 35, 36, 37 | 7, 11, 28, 32, 34 |
|            | Total power losses (kW) | 47.2 | 32.075 |
|            | Total losses reduction (kW) | - | 15.125 |
|            | Percentage reduction (%) | 0 | 32.04 |
|            | Total reactive power losses (kVAR) | 25.382 | 23.949 |
|            | Min. voltage (p.u.) | 0.9585 | 0.9715 |
|            | Max. voltage (p.u.) | 1.00 | 1.0049 |
| Normal load | Switch to be opened | 33, 34, 35, 36, 37 | 7, 11, 28, 32, 34 |
|            | Total power losses (kW) | 202.40 | 112.58 |
|            | Total losses reduction (kW) | 0 | 89.90 |
|            | Percentage reduction (%) | 0 | 44.42 |
|            | Total reactive power losses (kVAR) | 111.457 | 97.729 |
|            | Min. voltage (p.u.) | 0.9130 | 0.950 |
|            | Max. voltage (p.u.) | 1.00 | 1.0095 |
| Heavy load | Switch to be opened | 33, 34, 35, 36, 37 | 7, 11, 28, 32, 34 |
|            | Total power losses (kW) | 358 | 226.82 |
|            | Total losses reduction (kW) | - | 131.18 |
|            | Percentage reduction (%) | - | 36.64 |
|            | Total reactive power losses (kVAR) | 197.417 | 167.394 |
|            | Min. voltage (p.u.) | 0.8841 | 0.9245 |
|            | Max. voltage (p.u.) | 1.00 | 1.012 |
Figure 4. Voltage profile of 33-bus system for light load.

Figure 5. Voltage profile of 33-bus RDS for normal load.

Figure 6. Voltage profile of 33-bus RDS for heavy load.

Figure 7. Single line diagram after optimal network reconfiguration.
scenario, which occurs when the load increases at each bus at the same time was also considered. The results of this load level are shown in Figure 6 and Table 2. Figure 6 shows that the minimum voltage level is improved from 0.8841 p.u. to 0.9245 p.u. using the proposed NR approach. Reconfiguration of the network by using SPSO algorithm resulted in the closing of four tie-switches, namely: 33, 35, 36, and 37, while it also resulted in the opening of the sectionalizing switches. The opened switches are: 7, 11, 28, and 32 as shown in Figure 7. Figure 7 shows the single line diagram of the optimal NR in a 33-bus RDS.

The convergence value is the same for light load, normal load, and heavy load conditions as the convergence characteristics is shown in Figure 8. The results show that when the number of iterations increases, the objective function decreases. The objective function has a constant value of 0.06 from the 4th iteration up till the 100th iteration. The value is observed to give a high objective function of 1.0 in the 2nd iteration and this slightly changes to 0.95 in the 3rd iteration.

In Table 3, a comparison of the power loss and VP improvement of the proposed SPSO with EPSO algorithm for light, normal, and heavy loads is presented. The result presented in Table 3 show a 44.42% of loss reduction for SPSO for normal loads as compared to the EPSO algorithm for only normal load consideration. A further comparison was made with the proposed reconconfiguration method and other existing methods which used a 33 bus test system in Table 4. The comparative results with other methods used for DNR still show that the proposed SPSO algorithm outperforms other existing algorithms as shown in Table 4. The percentage reduction of real power losses of the test system are 32.04%, 44.42%, and 36.64%, whereas the reactive power loss percentage reductions are 28.409%, 32.859%, and 35.745% for light load, normal load, and heavy load, respectively. Also, the minimum voltage level in the worst case is enhanced from 0.8841 p.u. to 0.9510 p.u. The real power was enhanced for the light, normal, and heavy load conditions giving 99.341%, 97.289%, and 95.389%, respectively. The proposed method gave an average execution time of 4.02s in finding the optimal solution, which is faster than EPSO, PSO, and Evolutionary Programming (EP) presented in [8] which also used a 33-bus RDS and obtained 12.2s, 16s, and 55s, respectively [8]. The overall results shows that the

| Parameter | Light load | Normal load | Heavy load |
|-----------|------------|-------------|------------|
| Switched to be opened | 33, 34, 35, 36, 37 | 33, 34, 35, 36, 37 | 33, 34, 35, 36, 37 |
| Total power loss (kW) | 47.2 | 32.075 | 202.4 |
| Loss reduction (kW) | 0 | 15.125 | 82.0 |
| Loss reduction (%) | 0 | 32.04 | 40.5 |
| Voltage profile (VP) (p.u.) | 0.9585 | 0.9715 | 0.9130 |

Table 3. Performance measurement of the algorithm for power loss reduction for light, normal, and heavy loads.

| Method | Tie switch | Total power loss (kW) | Loss reduction (kW) | (%) Enhancement | Voltage profile (VP) improvement (p.u.) |
|--------|------------|-----------------------|---------------------|-----------------|-------------------------------------|
| Proposed SPSO | 33, 34, 35, 36, 37 | 112.58 | 89.90 | 97.289 | 0.037 |
| HSA [6] | 7, 10, 14, 36, 37 | 142.6816 | 60.01 | - | 0.027 |
| EPSO [8] | 33, 34, 35, 36, 37 | 120.7 | 82.0 | 40.5 | 0.077 |
| SPSO [14] | 33, 34, 35, 36, 37 | 202.6 | - | 31 | - |
| Firefly-DN, SBAT, SPSO [17] | 33, 34, 35, 36, 37 | 142.80, 140.42, 141.20 | 139.88, 140.48, 140.36 | 90, 40, 40 | 0.032 |
| IGA [20] | 7, 9, 17, 35, 37 | 142.80, 140.42, 141.20 | 139.88, 140.48, 140.36 | 90, 40, 40 | 0.032 |
| IPSO [20] | 7, 9, 17, 25, 35 | 94.28 | 94.51 | 0.033 |
| IGSO [20] | 33, 34, 35, 36, 37 | 94 | 94 | 0.033 |
| Improved adaptive imperialist competitive algorithm (IAICA) [21] | 7, 9, 14, 32, 37 | 139.55 | 63.14 | - | 0.027 |
| GA [22] | 7, 9, 14, 32, 37 | 139.55 | 63.14 | - | 0.027 |

Table 4. Comparison of the Proposed SPSO with other methods on a 33-bus system.
solutions provided by the proposed SPSO algorithm for the DNR problem gave optimal results compared with existing methods for DNR.

6. Conclusion

This paper presented a modified SPSO algorithm for optimal network reconfiguration (NR) for power loss minimization and voltage profile (VP) improvement in distribution systems. The optimization algorithm consists of a multi-objective function (MOF) and a number of constraints. Basic analyses carried out include load flow analysis, sensitivity factor analysis, and SPSO. Backward and forward load flow analysis was used to compute all the required parameters in the test system. The base case real power losses are 47.2 kW, 202.40 kW, and 358 kW for light load, normal load, and heavy load, respectively. The SPSO algorithm was used to select design variables depending on the optimal NR. The overall results show that the proposed algorithm was efficient in terms of reducing both the real and reactive power losses in the system.

Declarations

Author contribution statement

Ayodeji Olalekan Salau: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Yalew Werkie Gebru: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dessalegn Bitew: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

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References

[1] M.Y. Mon, Design and calculation of 5 MVAR shunt capacitor bank at 33kV bus in distribution substation, International Journal of Scientific Engineering and Technology Research 3 (15) (2014) 3259–3263.

[2] R. Magadum, T. Timanu, Minimization of power loss in distribution networks by different techniques, Int. J. Sci. Eng. Res. 3 (5) (2012) 521–527.

[3] R. Syahputra, I. Soesanti, M. Ashari, Performance enhancement of distribution network with DG integration using modified PSO algorithm, Journal of Electrical Systems 12 (11) (2016) 1–19.

[4] D.A. Bitew, A.O. Salau, Y. Gebru, Load flow and contingency analysis for transmission line outage, Arch. Electr. Eng. 69 (3) (2020) 273.

[5] A.E.B. Abu-Elanien, K.B. Shaban, Modern network reconfiguration techniques for service restoration in distribution systems: a step to a smarter grid, Alexandria Engineering Journal 57 (4) (2018) 3959–3967.

[6] R.S. Rao, S.V.L. Narasimham, M.R. Raju, A.S. Rao, Optimal network reconfiguration of large-scale distribution system using harmony search algorithm, IEEE Trans. Power Syst. 26 (3) (2011) 1080–1088.

[7] P.V.R. Rao, S. Sivanagaraju, P.V. Prasad, Network reconfiguration for loss reduction using plant growth simulation algorithm, in: International Conference on Power, Control and Embedded Systems, Allahabad, India, 2010, pp. 1–4.

[8] M.F. Sulaima, M.H. Jali, W.M. Bukhari, M.N.M. Nasir, H.I. Jaafar, Power distribution network reconfiguration by using EPSO for loss minimizing, Appl. Mech. Mater. 699 (2015) 809–815.

[9] Y.M. Shuaib, M.S. Kalavathi, C.G. Asir Rajan, Optimal reconfiguration in radial distribution system using gravitational search algorithm, Elec. Power Compon. Syst. 42 (7) (2014) 703–715.

[10] P.V. Prasad, S. Sivanagaraju, N. Sreenivasulu, Network reconfiguration for load balancing in radial distribution systems using genetic algorithm, Elec. Power Compon. Syst. 36 (1) (2007) 63–72.

[11] D. Shirmohammadi, H.W. Hong, Reconfiguration of electric distribution networks for resistive line losses reduction, IEEE Power Deliv. 4 (2) (1989) 1492–1498.

[12] M. Sedighizadeh, G. Shaghaghi-shahr, M.R. Aghamohammadi, M. Esmaili, A new optimal operation framework for balanced microgrids considering reconfiguration and generation scheduling simultaneously, International Transactions on Electrical Energy Systems (2020) 1–31.

[13] A.A.M. Raposo, A.B. Rodrigues, M.D.G. da Silva, Robust meter placement for state estimation considering distribution network reconfiguration for annual energy loss reduction, Elec. Power Syst. Res. 182 (2020) 106233.

[14] T.M. Khalil, A.V. Gorpinski, Reconfiguration for loss reduction of distribution systems using selective particle swarm optimization, Int. J. Multidisicp. Sci. Eng. 3 (6) (2012) 16–21.

[15] T.F. Agajie, A.O. Salau, E.A. Hailu, M. Sood, S. Jain, Optimal Sizing and Siting of Distributed Generators for Minimization of Power Losses and Voltage Deviation, 5th IEEE International Conference on Signal Processing, Computing and Control (ISPPCC), 2019, pp. 292–297.

[16] O.P. Mahela, S. Rani, O. Lalith, Optimal capacitor placement for loss reduction in radial distribution feeder, Med. Electr. Power Syst. 4 (6) (2013) 43–48.

[17] C. Gerez, L.I. Silva, E.A. Belati, A.J.S. Filho, E.C.M. Costa, Distribution network reconfiguration using selective firefly algorithm and a load flow analysis criterion for reducing the search space, IEEE Access 7 (2019) 67874–67888.

[18] R.S. Rao, K. Ravindra, K. Satish, S. Narasimham, Power loss minimization in distribution system using network reconfguration in the presence of distributed generation, IEEE Trans. Power Syst. 28 (1) (2012) 317–325.

[19] R. Tapia-Juarez, E. Espinosa-Juarez, Reconfiguration of radial distribution networks by applying a multi-objective technique, in: Proceedings on the International Conference on Artificial Intelligence, ICAI, 2015, pp. 131–137.

[20] N. Kanwar, N. Gupta, K.R. Niazi, A. Swarnkar, Improved meta-heuristic techniques for simultaneous capacitor and DG allocation in radial distribution networks, Electrical Power and Energy Systems 73 (2016) 653–664.

[21] S.H. Mirhoseini, S.M. Hosseini, M. Ghanbari, M. Ahmad, A new improved adaptive imperialist competitive algorithm to solve the reconfiguration problem of distribution systems for loss reduction and voltage profile improvement, Int. J. Electr. Power Energy Syst. 55 (2014) 128–143.

[22] A.M. Imran, M. Kowsalya, A new power system reconfiguration scheme for power loss minimization and voltage profile enhancement using fireworks algorithm, Int. J. Electr. Power Energy Syst. 62 (2014) 312–322.