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Power Loss Minimization and Voltage Stability Improvement in Electrical Distribution System via Network Reconfiguration and Distributed Generation Placement Using Novel Adaptive Shuffled Frogs Leaping Algorithm

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Abstract: This paper proposes a novel adaptive optimization algorithm to solve the network reconfiguration and distributed generation (DG) placement problems with objective functions including power loss minimization and voltage stability index (VSI) improvement. The proposed technique called Adaptive Shuffled Frogs Leaping Algorithm (ASFLA) was performed for solving network reconfiguration and DG installation in IEEE 33- and 69-bus distribution systems with seven different scenarios. The performance of ASFLA was compared to that of other algorithms such as Fireworks Algorithm (FWA), Adaptive Cuckoo Search Algorithm (ACSA) and Shuffled Frogs Leaping Algorithm (SFLA). It was found that the power loss and VSI provided by ASFLA were better than those given by FWA, ACSA and SFLA in both 33- and 69-bus systems. The best solution of power loss reduction and VSI improvement of both 33- and 69-bus systems was achieved when the network reconfiguration with optimal sizing and the location DG were simultaneously implemented. From our analysis, it was indicated that the ASFLA could provide better solutions than other methods since the generating process, local and global searching of this algorithm were significantly improved from a conventional method. Hence, the ASFLA becomes another effective algorithm for solving network reconfiguration and DG placement problems in electrical distribution systems.

Keywords: network reconfiguration; distributed generator installation; power loss reduction; voltage stability improvement; adaptive shuffled frog leaping algorithm

1. Introduction

In electrical distribution systems, the system power loss and voltage stability are the most significant factors indicating the power quality delivered to the costumers. These factors also depend on several uncertain circumstances such as distribution network expansion, load complexity and installation of distributed generation (DG) [1,2]. The power loss minimization in distribution systems is generally known as a main achievement in power system operations. Meanwhile, a rapid growth in load demand usually brings more voltage instability into the system. Therefore, several implementations have been proposed for power loss reduction and voltage stability enhancement e.g., network reconfiguration, DG installation, capacitor placement, installation of energy storage system, etc. [3–5]. Especially, the network reconfiguration and DG installation are the most efficient procedures to reduce the power loss and handle the unstable voltage profile, which can improve the overall performance of the distribution system [6].

Network reconfiguration is a process of altering the open/close status of sectionalizing and tie-line switches of the distribution system in order to change the topology of a system, and this process can improve the performance of the system according to different particular objectives and constraints [7]. Normally, the major objectives for network reconfiguration are power loss reduction, voltage profile improvement, voltage stability improvement and load balancing [8]. For example, A.M. Imran indicated that performing the system reconfiguration could essentially reduce the power loss while enhancing the voltage profile of the system [4].

The meta-heuristic is generally known as a capable approach to solve the network reconfiguration problems. Several meta-heuristic algorithms have been proposed in the literatures for solving these problems such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fireworks Algorithm (FWA), Cuckoo Search Algorithm (CSA), Ant Colony Search Algorithm (ACS), Runner-Root Algorithm (RRA) and Shuffled Frog Leaping Algorithm (SFLA) [4,6,9–12]. Especially, the SFLA, which mimics the culture of frogs while searching for food, is a recently proposed algorithm that indicates an efficient performance for solving the optimization problems due mainly to its high accuracy in local optimal searching [12–14]. In [12], it was found that the SFLA could efficiently find the optimal solution within fewer iterations than the GA and Simulated Annealing (SA). We noticed, however, that the performance SFLA could be further improved by developing the generating and searching mechanisms of this algorithm.

In addition, the DG installation in the electrical distribution system is extensively known as an effective method to improve the performance of distribution system. The DGs can be connected to the grid in which the main proposes are energy security and economical benefit. Installation of DGs could also yield power loss reduction, voltage profile and power quality improvement. Many meta-heuristic algorithms have been performed to solve DG placement problems such as Bacterial Foraging Optimization Algorithm (BFOA), Modified Teaching–Learning Based Optimization (MTLBO), Harmony Search Algorithm (HSA), SA and SFLA [14–16]. For example, Franco, J.F. indicated that the DG installation could significantly improve the power quality of both small-scale and large-scale distribution systems [16].

More recently, there were a few publications using a combination of network reconfiguration and DG placement to improve the performance of electrical distribution system, and the Adaptive Cuckoo Search Algorithm (ACSA), SFLA and FWA were the effective algorithms implemented in those problems [6,11,14]. It was shown that performing a combination of network reconfiguration and DG placement could efficiently provide remarkable power loss reduction, voltage stability index (VSI) improvement, energy cost and emission reduction of the distribution system [16–18].

Therefore, this paper proposes a novel adaptive algorithm called Adaptive Shuffled Frogs Leaping Algorithm (ASFLA) for solving the distribution network reconfiguration combined with the DG placement problem. This proposed algorithm performs an adaptive technique applied to SFLA in order to improve the generating and searching process of SFLA. The graph theory was also adapted in the proposed algorithm in order to avoid the mesh and node islanding conditions. The objective functions included power loss minimization and VSI improvement. The proposed ASFLA was tested in IEEE 33 and 69-bus distribution systems. The results obtained by the proposed algorithm were compared to other effective algorithms such as FWA, ACSA and SFLA.

2. Problem Formulation and Implementation of ASFLA in Electrical Distribution System

2.1. Objective Functions

In this work, the main objectives for network reconfiguration and DG allocation were to reduce the power loss and improve the VSI. The total power loss reduction, ΔP^{R}_{loss}, is firstly defined as a ratio between total power loss before network reconfiguration, P^{rec}_{loss}, and after network reconfiguration, P^{o}_{loss}, including the impact of DG installation, given as Equation (1).

$$\Delta P^{R}_{loss} = \frac{P^{rec}_{loss}}{P^{o}_{loss}} \tag{1}$$

The total active power loss, P_{loss}, of distribution system is normally calculated by a summation of losses in all branches, written as follow:

$$P_{loss} = \sum_{k=1}^{N_{br}} R_k \times \left(\frac{P_k^2 + Q_k^2}{V_k^2} \right) \tag{2}$$

where P_k, Q_k, R_k and V_k, are the active power, the reactive power, the resistance and the voltage magnitude of each branch number k, respectively. N_{br} is the total number of branches.

For the DG installation, the suitable sizing and location of DGs are normally taken into account. The appropriate sizing and location of DGs can be determined based on the VSI of the system. The VSI is a parameter used for indicating the voltage stability of distribution system, any node indicating high VSI identifies the less sensitive node to the voltage collapse. According to Figure 1, the VSI of node k + 1 is calculated as Equation (3) [17]:

$$VSI_{k+1} = |V_k|^4 - 4(P_{k+1}X_k - Q_{k+1}R_k)^2 - 4(P_{k+1}R_k - Q_{k+1}X_k)|V_k|^2 \tag{3}$$

where X_k is the reactance of branch k.

The objective Function (F) proposed in this work is minimizing total power loss and VSI deviation, as written in Equation (4) [17].

$$\min(F) = \Delta P^{R}_{loss} + \Delta VSI \tag{4}$$

where voltage stability deviation index (ΔVSI) is defined as Equation (5).

$$\Delta VSI = \max\left(\frac{1 - VSI_k}{1}\right); k = 2, \ldots, N_{bus} \tag{5}$$

The constraints subjected to network reconfiguration and DG installation problems include [6]:

- Size of DG: $0 \leq P_{DG} \leq P_{DG\_max}$ $(P_{DG\_max} \leq P_{load\_bus})$
- Position of DG: $2 \leq BUS \leq N_{bus}$
- Bus voltage: $0.95 \leq \left|V^k_{bus}\right| \leq 1.05$, where k = 1 to N_{bus}
- Branch current: $I^i_{DG} < I^{\mathrm{i}}_{limit}$, where i = 1 to N_{br}
- Power factor: $PF \geq 0.85$

where P_{DG} is the total power of DG, P_{DG_max} is the maximum total power of DG, P_{load_bus} is the total connected load at bus i, N_{bus} is the total number of bused, BUS is the bus number of the DG installation, V^k_{bus} is the bus voltage, I^i_{DG} is the current of the DG at branch i, I^{i}_{limit} is the is current limited at branch i.

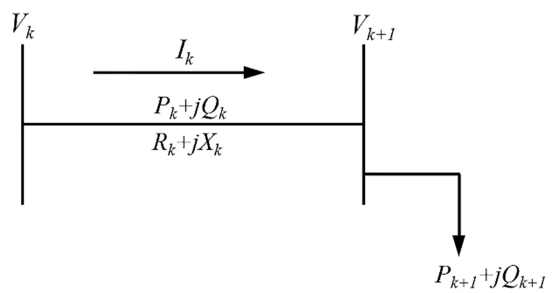

Figure 1. Single line of branch k of a radial distribution system.

2.2. Implementation of ASFLA in Network Reconfiguration and DG Placement Problems

The SFLA is a type of meta-heuristic algorithm which has been proposed by Eusuff, M. and Lansey, K. [12]. The SFLA mimics the culture of frogs while searching for food by randomly sitting on the pond, and then the evolution of an answer is achieved by exchanging frog groups for both sitting within a pond and between ponds. The outstanding ability of this algorithm is its high accuracy in local optimal searching. Several electrical researches have performed the SFLA to improve performance of electrical distribution system through network reconfiguration and DG allocation [16,18]. While using SFLA in network reconfiguration, however, there is a possible occurrence of a non-radial distribution system due to a generation of non-unity value of intersection loop switch. Accordingly, this weakness may sometimes cause high standard deviation and bad convergence. Therefore, we proposed an adaptive technique adapted to SFLA for avoiding the mesh and node islanding by using graph theory in the population generating process in order to guarantee a radial constraint. Also, we developed the shuffled process of ASFLA to improve the local and global searching ability. These adaptive techniques improved the capability of SFLA for solving network reconfiguration and DG placement problems.

The proposed algorithm called ASFLA was implemented for solving the network reconfiguration and DG placement, the procedures are described as following details:

- Step 1: Define the input data of the electrical distribution system.
- Step 2: Randomly generate the initial frog populations, as written in Equation (6).

$$\text{Population} = \begin{bmatrix} X_1 \\ X_2 \\ \cdots \\ X_N \end{bmatrix} \tag{6}$$

where N is the population of frogs defined as 90 in this work [19], $X_i = [x_{i,1}\, x_{i,2}\, x_{i,3} \ldots x_{i,n}]$ and $x_i = [sw_1 \ldots \mathrm{sw}_n, LoDG_1 \ldots LoDG_n, SizeDG_1 \ldots SizeDG_n]$.

sw_n is the number of opened sectionalizing or tie-line switches in loop n, $LoDG_n$ is the number of bus for DG installation and $SizeDG_n$ is the size of DG installed at bus n.

In the population generating process, the constraints including radial topology and every node connected after network reconfiguration were taken into account. So, we adapted the graph theory to the generating process in order to prevent an occurrence of an infeasible population, as the following details:

(1) Generate sw_n as the first opened switch where sw_n can be sectionalizing or tie-line switch in the loop n.

(2) Generate another opened switch sw_{n+1} by using graph theory under the following conditions:

  - If sw_n is not a member of the common switch between any loop n and loop $n + 1$, sw_{n+1} will be a member of loop $n + 1$.
  - If sw_n is a member of the common switch between any loop n and loop $n + 1$, sw_{n+1} will be member of loop $n + 1$ excluded a member of the common switch.
  - When a common switch in any loop connected to loop $n + 1$ is opened, sw_{n+1} will be a member of loop $n + 1$ excluded a member of the common switch of that loop.

1. Step 3: Rank the best to worst results obtained from Step 2 with regard to the objective function. The best result is defined as the 1st frog and the rest will follow.
2. Step 4: Rearrange the ranked frog results obtained from Step 3 into groups of frog called memplex. There are nine memplexes considered in the implementation, and accordingly the frog member in each memplex will be nine. The 1st to 9th frogs are respectively put into 1st to 9th memplex, afterwards the 10th to 18th frogs will be repeatedly put into 1st to 9th memplex and the rest will follow.

3. Step 5: The evolution of the frogs will be accomplished by replacing the worst frog of each memplex, X_w, by the new generated frog, X_{new}. We propose an adaptive technique for generating the X_{new} by improving the local and global searching of ASFA based on the previous obtained frogs. The X_{new} is generated by considering the behaviour of the best answer of all frogs, X_g, the best frog of each memplex, X_b, and the new randomly generated frog, X_{rand}, as given in Equation (7). The new population of frogs is generated using the information from both local and global searching which are the $rand(X_g^i - X_{rand}^i)$ term and the $X_{rand}^i + rand(X_g^i - X_b^i)$ term, respectively. The radial system constraint is taken into account while solving ASFLA.

$$X_{new}^i = X_{rand}^i + rand(X_g^i - X_b^i) + rand(X_g^i - X_{rand}^i) \tag{7}$$

4. Step 6: Update the locations and positions of frogs, and then repeat Steps 3–5 to obtain a specific number of iteration until the solution is satisfied.
5. Step 7: Finish.

3. Results and Discussion

In order to demonstrate the performance of proposed ASFLA for solving the network reconfiguration and DG installation in the electrical distribution system, this algorithm was implemented in IEEE 33-bus and 69-bus distribution systems. The number of installed DG was given as three sites, while the size of each DG unit was 0 to 2 MW since this condition is appropriate for 33- and 69-bus systems, as verified in the literature [16]. The results achieved by proposed ASFLA were compared to those of other methods including FWA, ACSA and SFLA which are efficient algorithms for solving similar problems. Seven scenarios were considered to determine optimal sequence of these problems as following details:

- Scenario 1: Base case system without network reconfiguration and DG installation.
- Scenario 2: The test system with only network reconfiguration.
- Scenario 3: The test system with only DG installation.
- Scenario 4: The test system with DG installation after network reconfiguration
- Scenario 5: The test system with network reconfiguration after DG installation.
- Scenario 6: The test system reconfigured simultaneously with DG installation.
- Scenario 7: The test system reconfigured simultaneously with DG installation and optimal DG location.

The results of each scenario were obtained by 100 iterations based on the objective function which minimizes the total power loss and VSI deviation, as shown in Equation (4). The best solutions of 33- and 69-bus distribution system are presented as follows.

3.1. 33-Bus Distribution System

As illustrated in Figure 2, the IEEE 33-bus electrical distribution system with 12.6 kV system voltage included 33 nodes, 37 branches, 32 sectionalizing switches and five tie switches [7]. The initial configuration of the system comprised of 32 normally closed sectionalize switches (switch number 1 to 32) and five normally opened tie switches (switch number 33 to 37). The total real power and reactive power loads were 3.72 MW and 2.3 MVAR, respectively, where an initial active power loss was 202.68 kW.

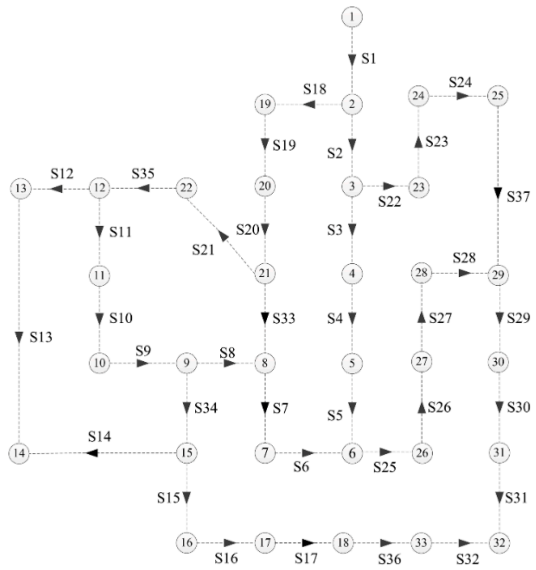

Figure 2. IEEE 33-bus distribution system [7].

The performance of the proposed ASFLA for solving network reconfiguration and DG installation in the 33-bus system is demonstrated in Table 1 with seven scenarios. From the results, it is clearly indicated that the power loss of the system was reduced from the initial value for all scenarios. The percentage power loss reduction of scenarios 2, 3, 4, 5, 6 and 7 was 30.93%, 67.00%, 74.50%, 72.76%, 73.80% and 75.57%, respectively, compared to the initial power loss. Also, the minimum voltage profile of the distribution system were clearly improved from the initial value of 0.9108 p.u. to 0.9413, 0.9781, 0.9864, 0.9830, 0.9814 and 0.9869 p.u. for Scenarios 2 to 7, respectively. Especially, the results of voltage stability indicates that the minimum VSI of distribution system was significantly improved from 0.6978 to 0.7878, 0.9161, 0.9474, 0.9359, 0.9284 and 0.9452 for Scenarios 2 to 7, respectively. It was shown that the highest the power loss reduction was found in Scenario 7, which implies that an inclusion of optimized bus location of DGs is necessary in solving network reconfiguration and DG placement in 33-bus system. When comparing the performance of proposed ASFLA to the FWA, ACSA and SFLA, it was found that the ASFLA could provide better power loss, voltage profile and the VSI for the distribution system than FWA, ACSA and SFLA for Scenarios 3 to 7. Meanwhile, those comparative algorithms provided similar results in Scenario 2, which indicated that every tested algorithms could efficiently find the best solutions of network reconfiguration problem.

The voltages profile and VSI of each bus in the 33-bus distribution system for seven scenarios are indicated in Figures 3 and 4, respectively. It is obviously shown that the voltage profile and VSI of each bus were significantly improved from the initial configuration by performing either the network reconfiguration or optimal sizing and location of the DG installation using the proposed ASFLA. Overall perspective indicates that Scenarios 4, 5 and 7 seem to have a better voltage profile and VSI than the other scenarios.

Table 1. Performance analysis of proposed ASFLA on the 33-bus system.

Scenario	Item	FWA	ACSA	SFLA	Proposed ASFLA
Base case (Scenario 1)	Opened switches	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37
	Power loss (kW)	202.68	202.68	202.68	202.68
	Minimum voltage (p.u.)	0.9108	0.9108	0.9108	0.9108
	Minimum VSI	0.6978	0.6978	0.6978	0.6978
Only reconfiguration (Scenario 2)	Opened switches	7, 9, 14, 28, 32	7, 9, 14, 28, 32	7, 9, 14, 28, 32	7, 9, 14, 28, 32
	Size of DG in MW (Bus number)	-	-	-	-
	Power loss (kW)	139.98	139.98	139.98	139.98
	Loss reduction (%)	30.93	30.93	30.93	30.93
	Minimum voltage (p.u.)	0.9413	0.9413	0.9413	0.9413
	Minimum VSI	0.7878	0.7878	0.7878	0.7878
Only DG Installation (Scenario 3)	Opened switches	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37
	Size of DG in MW (Bus number)	0.5897(14) 0.1895(18) 1.0146(32)	0.7798(14) 1.251(24) 1.3496(30)	0.5639(28) 0.3182(30) 0.5144(14)	0.5457(24) 0.9936(29) 1.2094(12)
	Power loss (kW)	88.68	74.26	83.37	66.87
	Loss reduction (%)	56.24	63.36	58.86	67.00
	Minimum voltage (p.u.)	0.9680	0.9778	0.9770	0.9781
	Minimum VSI	-	0.9118	0.9088	0.9161
DG installation after reconfiguration (Scenario 4)	Opened switches	7, 9, 14, 28, 32	7, 9, 14, 28, 32	7, 9, 14, 28, 32	7, 9, 14, 28, 32
	Size of DG in MW (Bus number)	0.5996(32) 0.3141(33) 0.1591(18)	1.7536(29) 0.5397(12) 0.5045(16)	0.7461(24) 0.3682(17) 0.0148(29)	0.0918(10) 0.6190(29) 0.5624(16)
	Power loss (kW)	83.81	58.79	80.42	51.68
	Loss reduction (%)	58.59	70.99	60.32	74.50
	Minimum voltage (p.u.)	0.9612	0.9802	0.9688	0.9864
	Minimum VSI	-	0.9264	0.9041	0.9474
Reconfiguration after DG installation (Scenario 5)	Opened switches	7, 34, 9, 32, 28	33, 9, 8, 36, 27	8, 11, 27, 33, 37	35, 34, 26, 37, 33
	Size of DG in MW (Bus number)	0.5897(14) 0.1895(18) 1.0146(32)	0.7798(14) 1.251(24) 1.3496(30)	0.5639(28) 0.3182(30) 0.5144(14)	0.5457(24) 0.9936(29) 1.2094(12)
	Power loss (kW)	68.28	62.98	71.86	55.1907
	Loss reduction (%)	66.31	68.92	64.54	72.76
	Minimum voltage (p.u.)	0.9712	0.9826	0.9763	0.9830
	Minimum VSI	-	0.9354	0.9123	0.9359
Simultaneous reconfiguration and DG Installation (Scenario 6)	Opened switches	7, 14, 11, 32, 28	7, 10, 13, 32, 28	9, 13, 27, 24, 33	9, 34, 27, 23, 33
	Size of DG in MW (Bus number)	0.5367(32) 0.6158(29) 0.5315(30)	0.4263(32) 1.2024(29) 0.7127(30)	0.4330(32) 1.0832(29) 0.0441(30)	0.7641(32) 0.0599(29) 0.9987(30)
	Power loss (kW)	67.11	63.69	68.64	53.10
	Loss reduction (%)	66.89	68.57	66.13	73.80
	Minimum voltage (p.u.)	0.9713	0.9786	0.9753	0.9814
	Minimum VSI	-	0.9202	0.9116	0.9284
Simultaneous reconfiguration, DG installation and location (Scenario 7)	Opened switches	-	33, 34, 11, 31, 28	5, 7, 33, 34, 35	35, 14, 26, 24, 33
	Size of DG in MW (Bus number)	- - -	0.8968(18) 1.4381(25) 0.9646(7)	0.9490(31) 0.1216(6) 1.2045(12)	0.2712(25) 0.6093(13) 0.8935(31)
	Power loss (kW)	-	53.21	64.77	49.51
	Loss reduction (%)	-	73.74	68.04	75.57
	Minimum voltage (p.u.)	-	0.9826	0.9765	0.9869
	Minimum VSI	-	0.9354	0.9147	0.9452

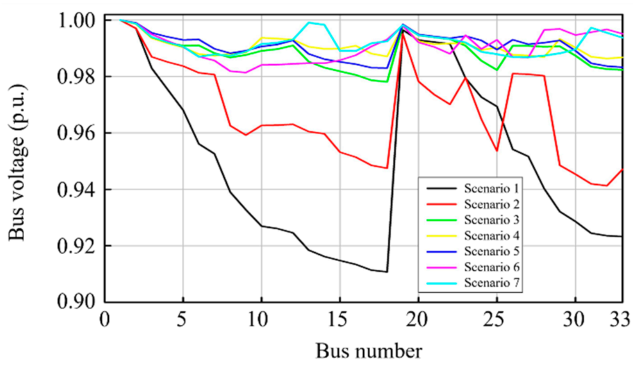

Figure 3. A comparison of bus voltage profile of 33-bus system for seven scenarios performed by proposed ASFLA.

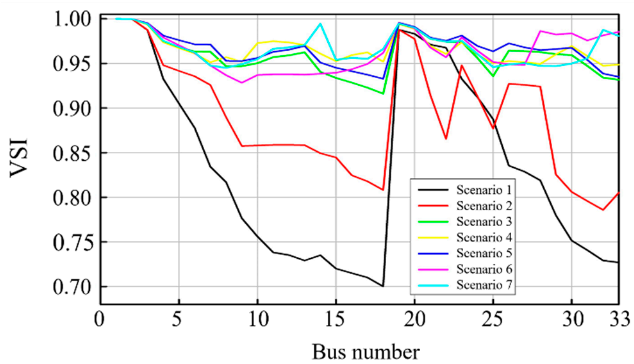

Figure 4. A comparison of VSI at each bus of 33-bus system for seven scenarios performed by proposed ASFLA.

3.2. 69-Bus Distribution System

The IEEE 69-bus electrical distribution system with 12.6 kV system voltage included 69 nodes, 73 branches, 68 sectionalizing switches and five tie switches, as demonstrated in Figure 5 [14]. The initial configuration of the system contained 68 normally closed sectionalize switches (switch number 1 to 68) and five normally opened tie switches (switch number 69 to 73). The real power and reactive power loads were totally 3.802 MW and 2.696 MVAR, respectively, where an initial active power loss was 224.89 kW.

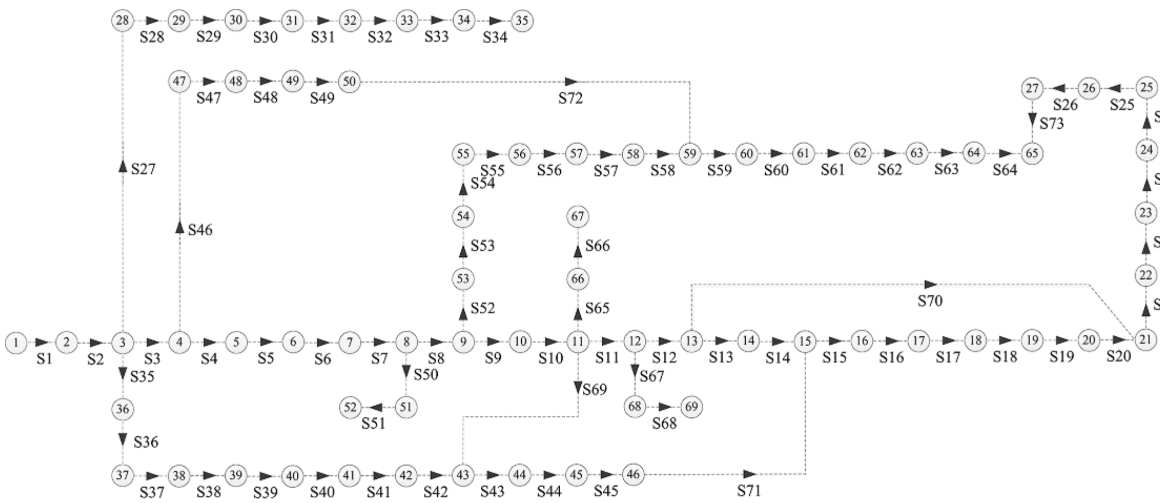

Figure 5. IEEE 69-bus distribution system [14].

The performance of the proposed ASFLA for solving network reconfiguration and DG installation in the 69-bus system is demonstrated in Table 2 with seven scenarios. From the results, it is obviously seen that the system power loss was reduced from an initial value for all scenarios. The percentage power loss reduction for Scenarios 2, 3, 4, 5, 6 and 7 was 56.16%, 69.13%, 84.55%, 84.10%, 83.68% and 84.90%, respectively, compared to the initial power loss. Furthermore, the minimum voltage profile of the distribution system were clearly improved from the initial value of 0.9092 p.u. to 0.9459, 0.9913, 0.9886, 0.9904, 0.9913 and 0.9915 p.u. for Scenarios 2 to 7, respectively. Moreover, the minimum VSI of distribution system was remarkably improved from 0.6859 to 0.8414, 0.9589, 0.9522, 0.9549, 0.9657 and 0.9659 for Scenarios 2 to 7, respectively. Similar to the 33-bus system, it was found that highest the power loss reduction was achieved by scenario 7, which implies that an inclusion of optimized bus location of DGs is necessary in solving network reconfiguration and DG installation in the 69-bus system. When comparing the performance of the proposed ASFLA to the FWA, ACSA and SFLA, it was observed that the ASFLA could provide better power loss, voltage profile and the VSI of the distribution system than the FWA, ACSA and SFLA for Scenarios 3 to 7. Meanwhile, those comparative algorithms provide equal results in Scenario 2, which was similar to that found in the 33-bus system.

Table 2. Performance analysis of proposed ASFLA on the 69-bus system.

Scenario	Item	FWA	ACSA	SFLA	Proposed ASFLA
Base case (Scenario 1)	Opened switches	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73
	Power loss (kW)	224.89	224.89	224.89	224.89
	Minimum voltage (p.u.)	0.9092	0.9092	0.9092	0.9092
	Minimum VSI	0.6859	0.6859	0.6859	0.6859
Only Reconfiguration (Scenario 2)	Opened switches	60, 70, 14, 57, 61	60, 70, 14, 57, 61	60, 70, 14, 57, 61	60, 70, 14, 57, 61
	Size of DG in MW (Bus number)	-	-	-	-
	Power loss (kW)	98.59	98.59	98.59	98.59
	Loss reduction (%)	56.16	56.16	56.16	56.16
	Minimum voltage (p.u.)	0.9459	0.9459	0.9459	0.9459
	Minimum VSI	0.8414	0.8414	0.8414	0.8414
Only DG installation (Scenario 3)	Opened switches	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73
	Size of DG in MW (Bus number)	0.4085(65) 1.1986(61) 0.2258(27)	0.6022(11) 0.3804(18) 2.000(61)	1.0887(57) 0.1673(63) 0.9809(26)	1.9626(62) 0.6274(16) 0.9939(40)
	Power loss (kW)	77.85	72.44	77.75	69.41
	Loss reduction (%)	65.39	67.79	65.43	69.13
	Minimum voltage (p.u.)	0.9740	0.9890	0.9752	0.9913
	Minimum VSI	-	0.9546	0.9472	0.9589
DG install after reconfiguration (Scenario 4)	Opened switches	69, 70, 14, 57, 61	69, 70, 14, 57, 61	69, 70, 14, 57, 61	69, 70, 14, 57, 61
	Size of DG in MW (Bus number)	1.7254(61) 0.4666(64) 0.3686(12)	1.7254(61) 0.4666(64) 0.3686(12)	0.4035(60) 0.7988(61) 0.9754(25)	0.2434(9) 1.0770(22) 0.9544(61)
	Power loss (kW)	37.23	37.23	45.52	34.74
	Loss reduction (%)	83.45	83.45	79.75	84.55
	Minimum voltage (p.u.)	0.9870	0.9870	0.9686	0.9886
	Minimum VSI	0.9390	0.9390	0.9454	0.9522
Reconfiguration after DG installation (Scenario 5)	Opened switches	69, 70, 14, 58, 64	69, 70, 14, 58, 64	54, 73, 15, 69, 12	57, 73, 13, 69, 12
	Size of DG in MW (Bus number)	0.6022(11) 0.3804(18) 2.000(61)	0.6022(11) 0.3804(18) 2.000(61)	0.659(57) 1.0887(63) 0.1673(26)	1.9626(62) 0.6274(16) 0.9939(40)
	Power loss (kW)	41.13	41.13	40.40	35.73
	Loss reduction (%)	81.1	81.1	82.04	84.10
	Minimum voltage (p.u.)	0.9828	0.9828	0.9752	0.9904
	Minimum VSI	0.9390	0.9390	0.9499	0.9549

Table 2. *Cont.*

Scenario	Item	FWA	ACSA	SFLA	Proposed ASFLA
Simultaneous Reconfiguration and DG installation (Scenario 6)	Opened switches	69, 70, 12, 58, 61	69, 70, 12, 58, 61	54, 61, 16, 69, 12	57, 64, 17, 69, 13
	Size of DG in MW (Bus number)	1.749(61) 0.1566(62) 0.4090(65)	1.749(61) 0.1566(62) 0.4090(65)	1.2532(61) 0.3260(62) 0.2147(65)	0.5453(61) 1.7169(62) 0.2243(65)
	Power loss (kW) Loss reduction (%) Minimum voltage (p.u.) Minimum VSI	40.49 82.00 0.9873 0.9403	40.49 82.00 0.9873 0.9403	41.84 81.40 0.9781 0.9466	36.70 83.68 0.9913 0.9657
Simultaneous Reconfiguration and DG installation and location (Scenario 7)	Opened switches	-	69, 70, 14, 58, 61	72, 56, 70, 69, 14	58, 73, 16, 69, 71
	Size of DG in MW (Bus number)	- - -	0.5413(11) 0.5536(65) 1.7240(61)	0.0193(59) 0.7004(60) 0.6668(61)	1.8384(5) 1.2154(62) 0.9603(11)
	Power loss (kW) Loss reduction (%) Minimum voltage (p.u.) Minimum VSI	- - - -	37.02 83.54 0.9869 0.9433	38.67 82.80 0.9778 0.9534	33.95 84.90 0.9915 0.9659

The voltages profile and VSI of each bus in the 69-bus distribution system for seven scenarios are indicated in Figures 6 and 7, respectively. It is obviously found that the voltage profile and VSI of each bus were significantly improved from the initial configuration by performing either network reconfiguration or optimal sizing and location of DG installation using the proposed ASFLA. Overall perspective indicates that Scenarios 4 and 7 seem to have better a voltage profile and VSI than the other scenarios.

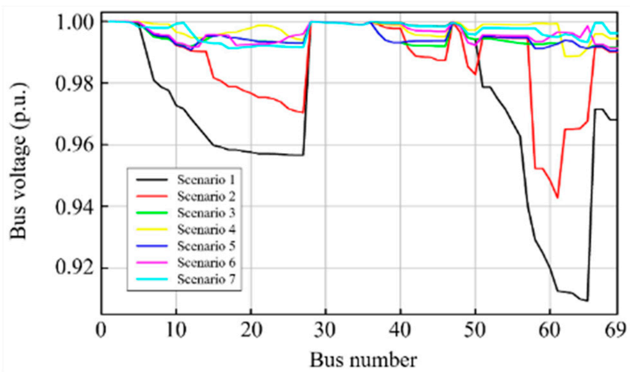

Figure 6. A comparison of bus voltage profile of 69-bus system for seven scenarios performed by proposed ASFLA.

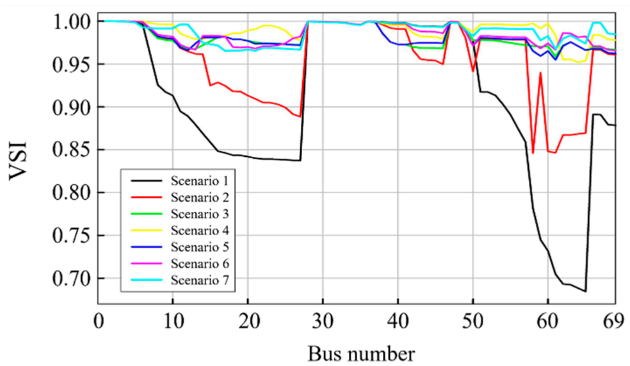

Figure 7. A comparison of VSI at each bus of 69-bus system for seven scenarios performed by proposed ASFLA.

From the results of the 33- and 69-bus distribution systems, it was clearly seen that the proposed ASFLA could provide more effective solutions than the other methods since we applied the graph theory to the generating process which could guarantee the feasible individual solutions during the population generating process. Furthermore, the evolutionary process of ASFLA was developed by generating the new solutions based on the local and global existing solutions, which essentially improved the accuracy of local and global searching along with eliminating local trapped solutions. Accordingly, the solutions provided by ASFLA became more accurate than the conventional algorithm. In addition, the computational time for evolutionary process of proposed ASFLA, could be longer if the number of opened switch and installed DG was increased, e.g., in the larger-scale system, since the new population of frogs was directly related to the number of opened switch and installed DG. However, the longer elapsed time played an insignificant role on the static problems demonstrated in this work. Hence, the ASFLA can indicate a faster searching ability and a more optimized solution for solving the network reconfiguration and DG placement problems.

4. Conclusions

In this paper, a novel optimization algorithm called ASFLA was proposed for solving the network reconfiguration and DG placement in IEEE 33- and 69-bus distribution systems with the objective functions including power loss minimization and VSI improvement. The adaptive techniques were applied to the conventional SFLA in order to improve the generating process, and the local and global searching of this algorithm. Seven different scenarios were considered in testing the ASFLA performance. It was found that the proposed ASFLA could provide better power loss, voltage profile and VSI than those given by the other efficient algorithms such as FWA, ACSA and SFLA in both 33- and 69-bus systems. The best power loss reduction and VSI improvement of 33- and 69-bus systems were found when the network reconfiguration with optimal sizing and location DG were simultaneously taken into account. Regarding to the best scenario, a power loss reduction of up to 75.57% and 84.90% could be reached in the 33- and 69-bus systems, respectively. Meanwhile, the VSI was improved from the initial value by about 35.45% and 40.82% for the 33- and 69-bus systems, respectively. Especially, the ability of ASFLA for improving the performance of 33- and 69-bus systems were better than other comparative algorithms since we developed the generating and evolutionary processes of proposed ASFLA. Hence, the proposed ASFLA algorithm can be efficiently utilized for solving the network reconfiguration and DG placement problems, which can significantly improve the performance of electrical power systems.

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