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Network reconfiguration and capacitor placement for power loss reduction using a combination of Salp Swarm Algorithm and Genetic Algorithm

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ABSTRACT:

This paper proposes electrical distribution system reconfiguration and capacitor placement for power loss reduction based on a combination of salp swarm algorithm and real-coded genetic algorithm (SSA-GA). The 33 bus distribution system was focused in network reconfiguration and capacitor placement problems. The simulation results obtained by the SSA-GA were compared with those of well-known algorithms such as Genetic Algorithm and Simulated Annealing. It was found that the performance of distribution system reconfiguration and capacitor placement by using SSA-GA is better than the other methods in terms of the quality of solutions and the average elapsed time. The explanation regarding to each algorithm profile was also given. From the results, it can be concluded that the SSA-GA is another great choice to reduce the electrical power loss which is an influential factor indicating the performance of smart grid system.

Keywords – Electrical distribution system, Electrical power loss reduction, Electrical system reconfiguration, Capacitor placement, Optimization methods,

I. INTRODUCTION

In the electrical distribution system, the power loss has been generally known as one of the most important factor indicating the system performance. Needless to say, the powerful distribution systems must have low power loss. Several methods have been proposed to reduce power loss in the distribution system i.e. conductor replacement and capacitor placement [1], distribution generator allocation [2], optimal energy storage system allocation [3] and network reconfiguration and capacitor placement [4]. The system reconfiguration is one of the popular methods for power loss reduction, especially in the smart grid system where the network topology can be certainly controlled, because of its outstanding properties such as low-cost investment and simple implementation. Especially, in the electrical distribution systems, there are normally open tie switches and normally closed sectionalizing switches. The topology of network can be changed by closing the normally open tie switches and opening the normally closed sectionalizing switches, which could significantly affect the total power loss of the system, this process is called system reconfiguration [5].

Another method to reduce electrical power loss in the distribution system is the capacitor placement [4]. Generally, an addition of installed capacitors in the electrical system provides a compensation of reactive power. The capacitor placement is the process to find the optimal location and size of the additional capacitor in order to obtain the most beneficial system. This method has been widely used in smart grid system where the capacitor sizing can be precisely controlled by the grid in order to improve the voltage profile and reduce power loss of the system, especially in the system containing a large variation of the load demand [4].

The meta-heuristic method has been generally known as the effective procedure to solve the reconfiguration problems for the power loss reduction [6]. Many different concepts of meta-heuristic method have been proposed to achieve the minimum power loss through system reconfiguration e.g. Particle Swarm Optimization (PSO) [7], Genetic Algorithm (GA) [8], Ant Colony Search Algorithm (ACSA) [9], Simulated Annealing (SA) [10], Cuckoo Search Algorithm (CSA) [11], Fireworks Algorithm (FA) [12] and Runner Root Algorithm (RRA) [13]. In addition, many meta-heuristic methods have been proposed in the literatures for optimizing the capacitor placement. In 2002, GA was applied to solve optimal capacitor allocation problem for power loss minimization [14]. After that, S. Singh performed the PSO for finding the optimal sizing and location of shunt capacitor in distribution system [15].

Recently, S. Sultana used Teaching Learning Based Optimization (TLBO) to optimize capacitor placement for minimizing the power loss and energy cost [16]. Especially, GA was found as a suitable algorithm for capacitor placement problem. Then, there are some researches combining the system reconfiguration problem with capacitor placement in order to maximize the system performance. The meta-heuristic methods such as GA, SA, ACO and PSO have been selected to solve those combined problems [4, 17]. However, a convergence property and a computation time for solving the network reconfiguration and capacitor placement problem can still be improved.

Lately, S. Mirjalili established a new optimization algorithm called Salp Swarm Algorithm (SSA) [18]. The inspiration of this method is the swarming behavior of salps when foraging and navigating in oceans. Particularly, the outstanding performance of this method to find the optimal solution of optimization problems, especially in the reconfiguration issue, is recently indicated [19].

Then, we propose an optimization of system reconfiguration and capacitor placement based on a combination of salp swarm algorithm and real-coded genetic algorithm (SSA-GA) for power loss reduction in 33 bus distribution system. The parameters representing the algorithm performance including the best power loss, the average power loss, the average elapsed time and the standard deviation were analyzed. In order to evaluate the performance of SSA-GA, the simulation results achieved by the SSA-GA are compared with those of well-known algorithms for power loss reduction such as GA and SA.

II. PROBLEM FORMULATION

The distribution system reconfiguration and capacitor placement problems are carried out in this work. The objective is to minimize the power loss without violating the constraints. The constraints of system reconfiguration and capacitor placement problem include no load can be left out of service, the radial structure of system must be maintained, bus voltage must be within upper and lower limits and branch current must be within the premising range. The objective function for the minimization of power loss can be expressed as follows [20]:

$$Minimize\ Objective = \sum_{i=1}^{nb} r_i \frac{(P_i^2 + Q_i^2)}{V_i^2} \tag{1}$$

Subjected to:

- All loads must be served.
- Radial system structure must be retained.

  $$\det(B) = 1\ or\ -1 \quad \text{(radial system)} \tag{2}$$
- Bus voltage should be between upper and lower limits.

  $$V^{\min} \le |V_j| \le V^{\max} \tag{3}$$
- Branch current should be within the premising range.

  $$0 \le |I_i| \le I_i^{\max} \tag{4}$$

where *Objective* is the objective function (kW), *nb* is total number of branches, r_i is resistance of branch *i*, P_i is active power at sending end of branch *i*, Q_i is reactive power at sending end of branch *i*, V_i is voltage at sending end of branch *i*, *B* is bus incidence matrix, V^{min} is bus minimum voltage limit (0.9 p.u.), $|V_j|$ is voltage magnitude of bus *j*, V^{max} is bus maximum voltage limit (1.0 p.u.), $|I_i|$ is current magnitude of branch *i*, I_i^{max} is maximum current limit of branch *i*.

III. OVERVIEW OF SALP SWARM ALGORITHM AND GENETIC ALGORITHM

The SSA imitates the behaviors of salp, this algorithm is known as a powerful algorithm for solving real-world problems with difficult and unknown search spaces [18]. The chain of salps is separated into two groups which are leader and followers. The leader navigates swarm whereas the followers trace each other. The position of each salps is defined in a *p*-dimensional search space where *p* is the number of variables of the problems. The two-dimensional matrix called *x* serve to store the position of all salps. The position of best salp (best solution) is assumed as the global optimum and assumed as the food source called *F*, that is chased by the chain of salps. In order to find a better solution, the food source will be updated during optimization by exploring and exploiting the search space [18]. So, the salps chain has move to the global optimal that will change in the range of iteration. The mathematical model to move salps chain can be written as follows [18]:

- To update the position of the leader.

$$x_j^1 = \begin{cases} F_j + c_1((ub_j - lb_j)c_2 + lb_j) & \text{when} \quad c_3 \geq 0.5 \\ F_j - c_1((ub_j - lb_j)c_2 + lb_j) & \text{when} \quad c_3 < 0.5 \end{cases} \tag{5}$$

where x_j^1 is the position of the first salp (the leader) in *j*th dimension, F_j is the position of a food source in the *j*th dimension (the swarm's target), ub_j is the upper bound of *j*th dimension, lb_j is the lower bound of *j*th dimension, c_2 and c_3 are random numbers uniformly generated in the interval of [0, 1], the coefficient c_1 is the main controlling parameter of SSA can be written as follows:

$$c_1 = 2e^{-(\frac{4l}{L})^2} \tag{6}$$

where *l* is the current iteration and *L* is the maximum number of iterations.

- To update the position of the followers.

$$x_j^i = \frac{1}{2}(x_j^i + x_j^{i-1}) \tag{7}$$

where $i \geq 2$ and x_j^i is the position of *i*th follower salp in *j*th dimension.

In addition, an overview and a solving procedure of Genetic Algorithm can be extensively found in many literatures [5, 8, 14].

IV. IMPLEMENTATION OF SALP SWARM ALGORITHM AND GENETIC ALGORITHM FOR SYSTEM RECONFIGURATION AND CAPACITOR PLACEMENT

The network reconfiguration in 33 bus distribution system using GA, SA and SSA are proposed in this work. The 33 bus distribution system is indicated in Fig. 1 [21]. The GA, SA and SSA algorithm have been programmed using MATLAB and run on a computer with Intel Core i7-7700-3.60 GHz and 16 GB DDR4 RAM.

1. Implementation of salp swarm algorithm and genetic algorithm for system reconfiguration

The procedures of system reconfiguration based on SSA can be expressed as follows:

- Step 1: Initialize the maximum number of iterations and load the parameters of system.
- Step 2: Initialize the salp population by regard upper and lower bounds and each salp is represented as the position of tie switches.
- Step 3: Compute the fitness of initial salps by using the following equation:

$$Minimize\ Fitness = \begin{cases} Objective \text{ (constraints are not violated.)} \\ Objective + Penalty \text{ (constraints are violated.)} \end{cases} \quad (8)$$

  where *Objective* is the objective function (kW) in (1) and *Penalty* is a large constant.

- Step 4: Set *F* (the food source) which is the position of the best search agent (best fitness of salp).
- Step 5: Start with iteration of 2, due to the first iteration was dedicated to calculate the fitness of salps.
- Step 6: Update c_1 by using (6).
- Step 7: Update the position of the leader by using (5).
- Step 8: Update the position of the follower by using (7).
- Step 9: Modify the salps based on the upper and lower bounds.
- Step 10: Calculate the fitness of each salp by using (8).
- Step 11: Update *F*.
- Step 12: Update the current iteration (iteration = iteration + 1).
- Step 13: Check the program stopping condition, if iteration < the maximum number of iterations, go to step 6, otherwise, go to step 14.
- Step 14: End.

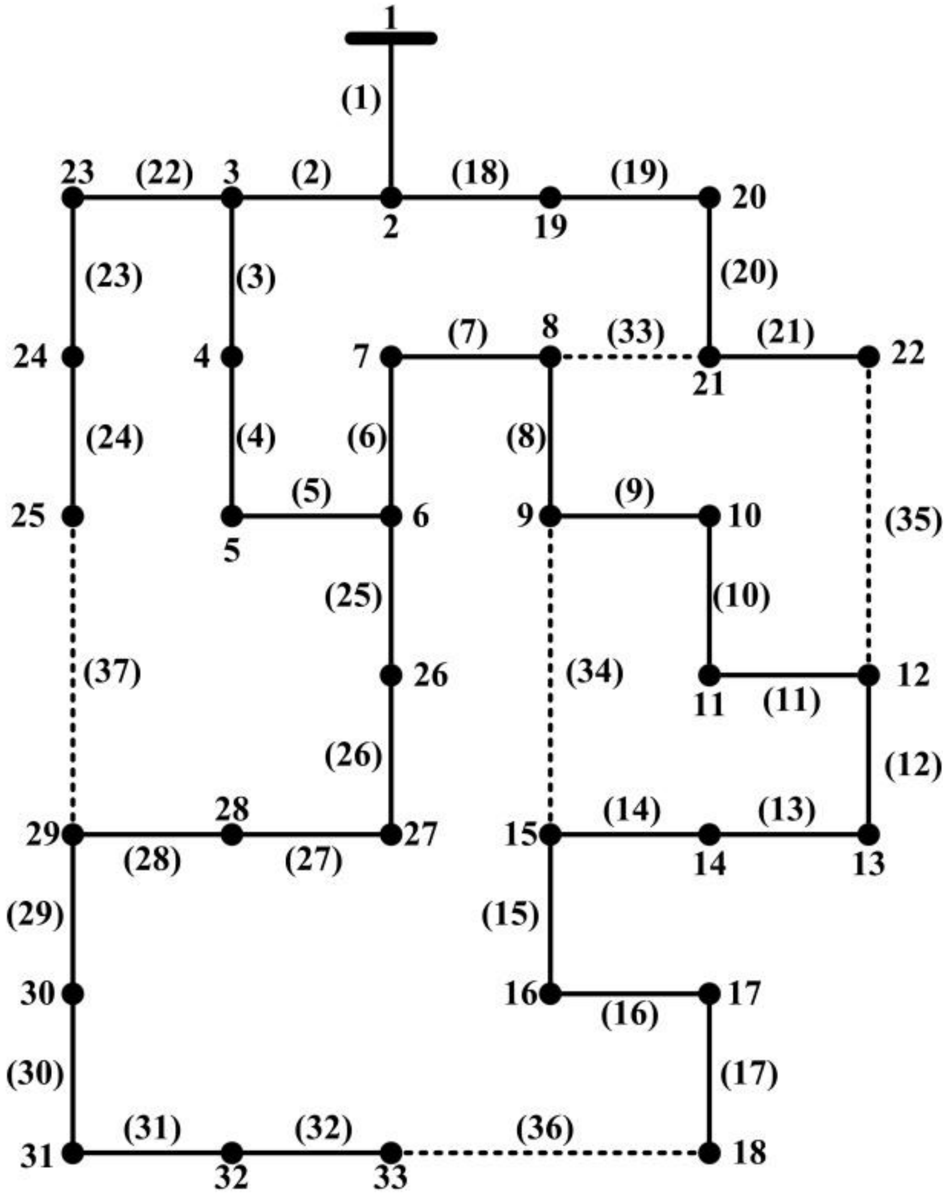

Figure 1. The 33 bus distribution system [21]

2. Implementation of salp swarm algorithm and genetic algorithm for capacitor placement

The procedures of capacitor placement based on SSA can be expressed as follows:

- Step 1: Initialize the maximum number of iterations and load the parameters of distribution system.
- Step 2: Initialize the salp population by regard upper and lower bounds and each

salp is represented as the size of installed capacitor. In order to find the location of installed capacitor, the dimension of search agents are set equal to the number of candidate bus.

- Step 3: Calculate the fitness of initial salps by using (8).
- Step 4: Initialize *F* (the food source) which is a position of best search agent (best fitness of salp).
- Step 5: Initialize with iteration of 2, due to the first iteration was dedicated to calculate the fitness of salps.
- Step 6: Update c_1 by using (6).
- Step 7: Update the position of the leader by using (5).
- Step 8: Update the position of the follower by using (7).
- Step 9: Modify the salps based on the upper and lower bounds.
- Step 10: Calculate the fitness of each salp by using (8).
- Step 11: Update *F*.
- Step 12: Update the current iteration (iteration = iteration + 1).
- Step 13: Check the program stopping condition, if iteration < the maximum number of iterations, go to step 6, otherwise, go to step 14.
- Step 14: End.

In addition, the procedure for implementing Genetic Algorithm to the reconfiguration and capacitor placement problems can be obtained in previous studies [8, 14].

V. TEST RESULTS

1. Optimizing setting parameter of SSA for system reconfiguration and capacitor placement problems

In order to maximize performance of SSA for solving the reconfiguration and capacitor placement problem, the main controlling parameter of this algorithm needs to be firstly optimized individually for each problem.

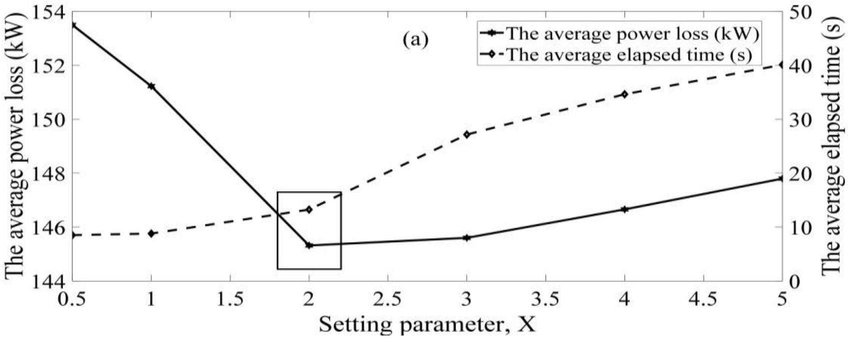

Figure 2(a)

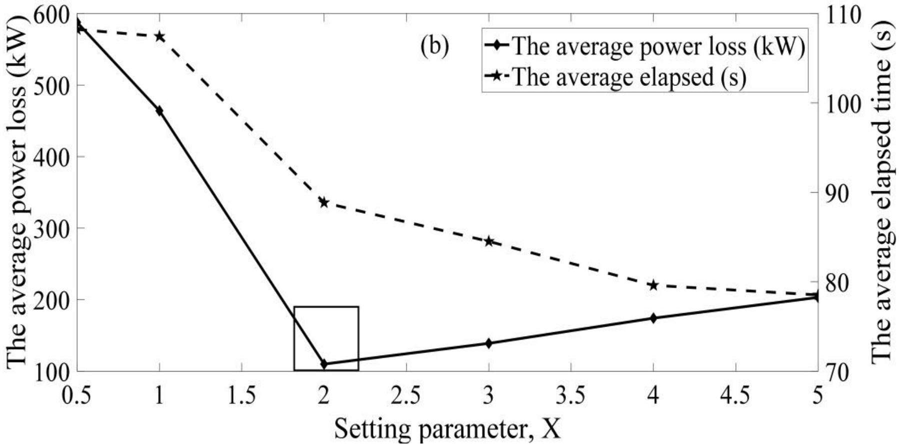

Figure 2(b)

Figure 2. The average power loss and elapsed time of 33 bus system as a function of setting parameter *X* of SSA for (a) the system reconfiguration and (b) the capacitor placement problem.

Fig. 2(a) and 2(b) respectively show the average power loss and elapsed time of 33 bus after system reconfiguration and capacitor placement as a function of *X* in the controlling parameter, c_1, given as $c_1 = 2e^{-(\frac{Xl}{L})^2}$. The results indicated in Fig. 2 are obtained by repeatedly solving the algorithm by 100 runs. It is observed that the average power loss and elapsed time become optimal at $X = 2$ for both reconfiguration and capacitor placement problems, then we set $X = 2$ in the simulations using SSA for network reconfiguration and capacitor placement.

2. System reconfiguration and capacitor placement of 33 bus distribution system

As illustrated in Fig. 1, the 33 bus test system consist 37 branches and 5 tie switches. It was initialized by M. Baran and F. Wu where the system data were also given [21].

The normally open switches are 33, 34, 35, 36, 37 and the initial power loss is 202.70 kW. The parameters of GA, SA, SSA and SSA-GA for network reconfiguration are defined as follows:

- The GA parameters: population is 20, maximum-iteration is 150, crossover rate is 0.70 and mutation rate is 0.30.
- The SA parameters: maximum-iteration is 200, sub-iteration is 15, initial temperature is 1000 and temperature reduction ratio is 0.95.
- The SSA parameters: population is 20, maximum-iteration is 200 and c_1 is adopted from (6) as $2e^{-(\frac{2l}{L})^2}$.
- The SSA-GA parameters: population is 20, maximum-iteration is 200 and c_1 is adopted from (6) as $2e^{-(\frac{2l}{L})^2}$.

In capacitor placement, types of capacitors include 300, 600, 900, 1200, 1500 and 1800 kVAR. The parameters of GA, SA, SSA and SSA-GA for capacitor placement are expressed as follows:

- The GA parameters: population is 60, maximum-iteration is 150, crossover rate is 0.70 and mutation rate is 0.30.
- The SA parameters: maximum-iteration is 50, sub-iteration is 200, initial temperature is 1000 and temperature reduction ratio is 0.95.
- The SSA parameters: population is 60, maximum-iteration is 150 and c_1 is adopted from (6) as $2e^{-(\frac{2l}{L})^2}$.
- The SSA-GA parameters: population is 60, maximum-iteration is 150, crossover rate is 0.70 and mutation rate is 0.30.

Table 1. The simulation results obtained from different algorithms in 33 bus system

Type of problems	System parameters	Solving algorithms			
		Real-coded GA	SA	SSA	SSA-GA
Only reconfiguration	initial configuration	202.70	202.70	202.70	202.70
	Best power loss (kW)	139.55	139.55	139.55	139.55
	Worst power loss (kW)	186.96	199.31	160.12	160.12
	Average power loss (kW)	154.39	152.39	145.32	145.32
	Average loss reduction (%)	23.83	24.82	28.31	28.31
	Average elapsed time (s)	42.61	25.94	13.25	13.25
	Standard deviation	16.79	13.81	4.54	4.54

Only capacitor placement	initial configuration	202.70	202.70	202.70	202.70
	Best power loss (kW)	130.21	130.81	131.34	130.21
	Worst power loss (kW)	131.64	134.60	471.56	131.64
	Average power loss (kW)	130.59	132.82	175.79	130.59
	Average loss reduction (%)	35.57	34.47	13.28	35.57
	Average elapsed time (s)	64.78	106.75	81.55	64.78
	Standard deviation	0.26	0.79	54.25	0.26
Reconfiguration with capacitor placement	initial configuration	202.70	202.70	202.70	202.70
	Best power loss (kW)	90.16	92.52	93.31	90.05
	Worst power loss (kW)	126.64	252.90	267.84	105.03
	Average power loss (kW)	101.26	102.86	129.73	94.32
	Average loss reduction (%)	50.04	49.26	36.00	53.47
	Average elapsed time (s)	110.07	127.07	87.37	77.86
	Standard deviation	11.56	17.30	37.29	2.72

Table 1 indicates the initial configuration, best power loss, average power loss, worst power loss, elapsed time and standard deviation of the 33 bus test system after solving reconfiguration, capacitor placement and reconfiguration with capacitor placement problems by using different algorithm.

From the simulation results, it is observed that the SSA algorithm could provide better value of the average power loss, average elapsed time and standard deviation than that of the others only for reconfiguration problem. The reason is because the SSA is quite effective for solving system reconfiguration problem since it is a powerful algorithm for solving real-world problems with difficult and unknown search spaces [18]. In only capacitor placement case, it is seen that the best power loss, average power loss, average elapsed time and standard obtained by the GA algorithm are better than the other methods. This is because the capacitor placement is the optimization problem which has large search space. Then the GA, which is typically suitable for solving a problem with large solution space without trapped in local optimal, could indicate as the most effective for solving the capacitor placement [6]. For the reconfiguration with capacitor placement problem, GA indicates the best power loss reduction and standard deviation whereas the SSA could provide the fastest simulation elapsed time.

Then, it can be concluded that the SSA algorithm indicates the most outstanding performance for solving the system reconfiguration problem whereas GA method is appropriate to solve the capacitor placement problem. From discussion above, we propose a novel combining technique for minimizing the power loss in electrical distribution system called SSA-GA. This proposed technique performs the outstanding property of SSA and GA in solving reconfiguration and capacitor placement problems, respectively. From the results in reconfiguration and with capacitor placement case, it is obviously found that the best power loss, average power loss, average elapsed time and standard deviation obtained by the SSA-GA are better than those of the others. Accordingly, the overall performance of SSA-GA for solving the reconfiguration and capacitor placement problem is better than the GA, SA and SSA methods.

Table 2. The simulation results obtained SSA-GA in 33 bus system

Items	Initial configuration	Reconfiguration with capacitor placement	
Tie switches	33, 34, 35, 36, 37	7, 9, 14, 32, 37	
The power loss (kW)	202.70	90.05	
Minimum voltage (p.u.)	0.913 (Bus 18)	0.961 (Bus 33)	
Maximum voltage (p.u.)	1.000 (Bus 1)	1.000 (Bus 1)	
The elapsed time (s)	-	81.72	
Bus number	Bus voltage (p.u.)	Capacitor placed (kVAR)	Bus voltage (p.u.)
1	1.000	-	1.000
2	0.997	-	0.998
3	0.983	-	0.991
4	0.975	-	0.987
5	0.968	-	0.985
6	0.950	300	0.979
7	0.946	-	0.978
8	0.941	-	0.974
9	0.935	300	0.972
10	0.929	-	0.976
11	0.928	-	0.976
12	0.927	300	0.977
13	0.921	-	0.974
14	0.919	-	0.973
15	0.917	-	0.966
16	0.916	-	0.965
17	0.914	-	0.962
18	0.913	-	0.961
19	0.997	-	0.996
20	0.993	-	0.985

Items	Initial configuration	Reconfiguration with capacitor placement	
21	0.992	-	0.982
22	0.992	-	0.980
23	0.979	300	0.988
24	0.973	-	0.983
25	0.969	300	0.981
26	0.948	-	0.978
27	0.945	-	0.976
28	0.934	-	0.971
29	0.926	-	0.968
30	0.922	600	0.966
31	0.918	300	0.964
32	0.917	-	0.964
33	0.917	-	0.961

Table 2 shows the parameters of 33 bus test system after reconfiguration with capacitor placement by using SSA-GA. The tie switches, bus voltage of each bus number and installed capacitor location are illustrated. It is found that the power loss is improved from their initial value about 55% and the overall voltage profile is improved. Hence, a proposed SSA-GA technique is another effective method for reducing the power loss in electrical distribution system, especially in the smart grid system where the network reconfiguration and capacitor placement can be certainly handled. However, it is noted that our proposed SSA-GA technique still needs to be tested in the large-scale system in order to verify the performance of this algorithm for solving more complexity problems.

VI. CONCLUSION

In this work, the system reconfiguration and capacitor placement of 33 bus electrical distribution system for power loss reduction by using SSA-GA are proposed. The simulation results achieved by SSA-GA are compared with those of GA, SA and SSA algorithms. It was found that the best power loss, average power loss, average elapsed time and standard deviation obtained by SSA-GA are remarkably less than the other methods. Then, the performance of SSA-GA for solving the reconfiguration and capacitor placement problems is better than GA, SA and SSA algorithms. Accordingly, the SSA-GA becomes the great choice for solving network reconfiguration and capacitor placement problems, which can be handled using smart grid system, in order to improve the performance of electrical distribution system.

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