



Optimum Simultaneous Distributed Generation Units Insertion and Distribution Network Reconfiguration Using Salp Swarm Algorithm

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KEY WORDS

Power Losses, Salp Swarm Algorithm, Network Reconfiguration, voltage profile (VP), distribution system (DS).

ABSTRACT

Contemporary researches offer that most researchers have concentrated on either network reconfiguration or Distributed Generation (DG) units insertion for boosting the performance of the distribution system (DS). However, very few researchers have been studied optimum simultaneous distributed generation units insertion and distribution networks reconfiguration (OSDGIR). In this paper, the stochastic meta-heuristic technique belong to swarm intelligence algorithms is proposed. Salp Swarm Algorithm (SSA) is inspired by the behavior of salps when navigating and foraging in the depth of the ocean. It utilized in solving OSDGIR. The objective function is to reduce power loss and voltage deviation in the Distribution System. The SSA is carried out on two different systems: IEEE 33-bus and local Iraqi radial (AL-Fuhood distribution network). Three cases are implemented; only reconfiguration, only DG units insertion, and OSDGIR. Promising results were obtained, where that power loss reduced by 93.1% and recovery voltage index enhanced by 5.4% for the test system and by 78.77% reduction in power loss and 8.2% improvement in recovery voltage for AL-Fuhood distribution network after applying OSDGIR using SSA. Finally, SSA proved effectiveness after an increase in test system loads by different levels in terms of reduced power loss and voltage deviation comparison with other methods.

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1. INTRODUCTION

Network Reconfiguration (NR) and Distributed Generator (DG) are considered major techniques used to minimize system power losses (PL), improve the voltage profile (VP) and mitigation of overloads on heavy buses in the Distribution System (DS). Consequently, the overall system capability will be enhanced [1]. Radial Distribution System Reconfiguration (RDSR) is the operation of altering the status of opening and closing of switches (sectionalizing and tie) by the operator either automatically or manually, considering two conditions. Firstly, the structure of the system remains radial, and secondly, operational constraints are validated without any additional expenses [2].

There are many different optimization methods that have been proposed for solving the RDSR problems. In reference [3], proposed fireworks algorithms (FWA) for improving PL reduction and VP of DS. Researchers in [4] proposed modified particle swarm optimization (MPSO) for finding the optimum solutions in terms of minimum PL and minimum voltage deviation (VD) in DS. It tested on two test systems, and different loads are considered.

In [5] proposed a meta-heuristic approach based on a chaotic stochastic fractal search algorithm (CSFSA) for solving DS to reduce PL and VD. On the other side, the insertion of distributed generation DG units into DS has a positive impact in terms of minimization of line PL, and VD provided that placement and size of DG units be appropriate [6, 7].

Several methods have been proposed to solve the complicated optimization problem of DG insertion. In [8], analytical approaches based on theoretical analysis to find the optimal position to accommodate a DG to reduce the PL of DS were proposed. Optimal sizing of DG is not included and only a single DG unit. Researchers in [9] proposed a Genetic Algorithm (GA) for solving the optimal size and position of DG units in DS with different load levels and utilized one DG unit. Particle swarm optimization is proposed in [10] to optimally identify the location and size of multi-dispersed generators on various DS.

Optimum simultaneous Reconfiguration and DG units insertion (OSDGIR) provide significant gains of DS. Its operation to integrate static and dynamic mechanisms in DS to give better results with regard to lower PL and reduced VD [11]. Various sets of optimization methods have been proposed to solve this kind of complex problem. In reference [12], the proposed Harmony search algorithm (HSA) is employed for solving OSDGIR in DS to reduce PL and improve VP.

Authors in [13] proposed an artificial bee colony (ABC) as a new optimization algorithm for solving OSDGIR in DS to reduce PL and VD. The authors in [14], proposed a hybridized Harmony Search Algorithm (HSA) and teaching learning-based optimization (TLBO) to develop a comprehensive teaching-learning harmony search optimization algorithm (CTLHSO) for solving OSDGIR and the aims are to reduce PL and improve VD with considered different load levels.

In this paper, the problem formularization will be discussed in section (2) and include power flow equations, objective function, new recovery voltage index concept, and limitation of constraints that were taken in this work. In section (3), a proposed technique outlined used in this work.

In section (4), the simulations and implemented four cases on both test system IEEE 33-bus and AL-Fuhood distribution systems. Also, in the same section, results obtained are compared with other methods and discussion of these results. Finally, section (5) is the conclusion of this paper.

2. PROBLEM FORMULATION

In Figure 1, a single line of RDS. A-line section (LS) is connected between bus (u) and bus (u+1) with impedance $(R_{(u,u+1)} + jX_{(u,u+1)})$ and the load $(PL_{(u+1)} + jQL_{(u+1)})$ at the bus (u+1).

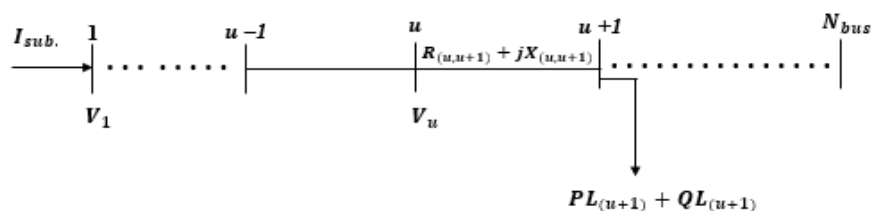


Figure 1: Single line of radial distribution system [15]

The load flow is calculated to find the power loss equation between bus (u) and bus (u+1) in terms of LS elements and parameters [15,16].

$$P_{(u+1)} = P_{(u)} - PL_{(u+1)} - \frac{(P_u^2 + Q_u^2)}{|V_{(u)}|^2} * R_{(u,u+1)} \quad (1)$$

$$Q_{(u+1)} = Q_{(u)} - QL_{(u+1)} - \frac{P_u^2 + Q_u^2}{|V_{(u)}|^2} * X_{(u,u+1)} \quad (2)$$

$$|V_{(u+1)}|^2 = |V_{(u)}|^2 - 2[R_{(u,u+1)} * P_{(u)} + X_{(u,u+1)} * Q_{(u)}] + \frac{(P_u^2 + Q_u^2)}{|V_{(u)}|^2} * [R_{(u,u+1)}^2 + X_{(u,u+1)}^2] \quad (3)$$

where:

$P_{(u+1)}$: active power flowing in bus (u+1)

$Q_{(u+1)}$: reactive power flowing in bus (u+1)

$P_{(u)}$: active power flowing in bus (u)

$Q_{(u)}$: reactive power flowing in bus (u)

$V_{(u+1)}$: voltage at bus (u+1)

$V_{(u)}$: voltage at bus (u)

$R_{(u,u+1)}$: resistance of line section between bus (u) and bus (u+1)

$X_{(u,u+1)}$: reactance of line section between bus (u) and bus (u+1)

Then, the real PL of LS [15,16]:

$$P_{(u,u+1)}^{loss} = I_u^2 * R_{(u,u+1)} \quad (4)$$

$$P_{(u,u+1)}^{loss} = \frac{(P_u^2 + Q_u^2)}{|V_{(u)}|^2} * R_{(u,u+1)} \quad (5)$$

Where I_u is the current flowing in bus (u)

So, the total PL is:

$$P^{Tloss} = \sum_{u=1}^{N_{bus}-1} P_{(u,u+1)}^{loss} \quad (6)$$

Consequently,

$$MOV = \min[P^{Tloss}] \quad (7)$$

where MOV is the minimum objective value (fitness).

One of the positive impacts of OSDGIR process improves the voltage profile in which the voltage deviation (VD) is reduced to as less as possible (ideally VD is zero), that can be given by:

$$VD = \min\left(\frac{V_1 - V_u}{V_1}\right) \quad (8)$$

Where: $u = 2, \dots, N_{bus}$ & $V_1 = 1 p.u.$

In this work, Recovery Voltage Index (RVI) is utilized; RVI is the ratio of buses voltages improvement after applying reconfiguration or DG units insertion or both because the improvement of voltage profile may not have happened in all buses but only in some of them. RVI mathematically modeled as follow:

$$RVI (\%) = \frac{V_{av\ after} - V_{av\ before}}{V_{av\ before}} \quad (9)$$

where: $V_{av\ before}$ is the average voltage of bus voltages before applying reconfiguration or DG units insertion or both (base case). $V_{av\ after}$ is the average voltage of bus voltages after applying reconfiguration or DG units' insertion or both.

I. Active power loss of system after reconfiguration

Eq. (6) is amended after reconfiguration to become [14]:

$$P_r^{Tloss} = \sum_{u=1}^{Nbus-1} P_{r(u,u+1)}^{loss} \quad (10)$$

Where:

P_r^{Tloss} : total active power loss after system reconfiguration.

$P_{r(u,u+1)}^{loss}$: active power loss between bus (u) and bus (u+1).

II. Active power loss after DG insertion

After insertion of DG units, the real and reactive power of demands at the bus (u+1) are changed as follows [14]:

$$P_{L(u+1)}^{DG} = PL_{(u+1)} - P_{(u+1)}^{DG} \quad (11)$$

$$Q_{L(u+1)}^{DG} = QL_{(u+1)} - Q_{(u+1)}^{DG} \quad (12)$$

where:

$P_{L(u+1)}^{DG}$: Active demand at the bus (u+1) after insertion of DG units

$P_{(u+1)}^{DG}$: Active power supplied by DG units

$Q_{L(u+1)}^{DG}$: Reactive demand at the bus (u+1) after insertion of DG units

$Q_{(u+1)}^{DG}$: Reactive power supplied by DG units

And power loss expressed in eq. (6) become as follow:

$$P_{DG}^{Tloss} = \sum_{u=1}^{Nbus-1} P_{DG(u,u+1)}^{loss} \quad (13)$$

where,

P_{DG}^{Tloss} : The total power loss of the system after DG insertion.

III. Active power loss after OSDGIR

Expression of power loss in Eq. (6) will be amended after OSDGIR as follow:

$$P_{r,DG}^{Tloss} = \sum_{u=1}^{Nbus-1} P_{r,DG(u,u+1)}^{loss} \quad (14)$$

where, $P_{r,DG}^{Tloss}$ is the total active PL of RDS after OSDGIR.

IV. Constraints

To accomplish (OSDGIR) in RDS, several constraints must be maintained anyway. The most important of them is to keep the topology of system radial that all loads are served; mathematical formulations in the following subsections represent others.

A. Power equilibrium constraint

Power Equilibrium Constraints (PEC) refer to that summation of total powers flowing into RDS (which is consists of power supplied by the substation and that supplied by DG) must be equal to the summation of the overall loads and overall PL of RDS (equality constraint).

$$\sum_{i=1}^H P_{DG,i} + P_{sub} = P_{loads} + P_{losses} \quad (15)$$

where: H is the maximum number of DG units, $P_{DG,i}$ is power supplied by DG, P_{sub} is power supplied by the substation, P_{loads} is the power received by loads, and P_{losses} is the power losses dissipated by lines.

B. Limits of bus voltage

In all operational cases in this work, optimum reconfiguration, OSDGIR, the bus voltage must be within suitable. The bus voltage must be within suitable limits, which are between the minimum and maximum limits (inequality constraint).

$$0.9 \leq V_u \leq 1.0 \quad (16)$$

C. Limits of DG ratings

Ratings of DG units must be within suitable bounds (inequality constraint), they usually less than the summation of loads and losses of the system to ensure no reverse power flow towards substation:

$$P_{min}^{DG} \leq P_{DGz} \leq P_{max}^{DG} \quad (17)$$

where: z is the number of allocated DG units in DS ($z= 1, 2, 3, \dots$), P_{min}^{DG} is minimum bound of DG rating and P_{max}^{DG} is the maximum bound of the DG rating.

3. SALP SWARM ALGORITHM

The proposed Salp Swarm Algorithm (SSA) is a stochastic meta-heuristic technique belong to swarm intelligence algorithms. In 2017 [17], Mirjalili et al. are proposed this algorithm for solving several optimization problems in the field of engineering design. It proved its efficiency and effectiveness by applying it to two major issues in the real world related to engineering design, namely the design of marine propeller and airfoil. The proposed algorithm is inspired by the behavior of salps when navigating and foraging in the depth of oceans. The salp shape is shown in Figure 2 (a). The movement of salps is in the form of a swarm called the Salp Chain (SCH), as shown in Figure 2 (b).

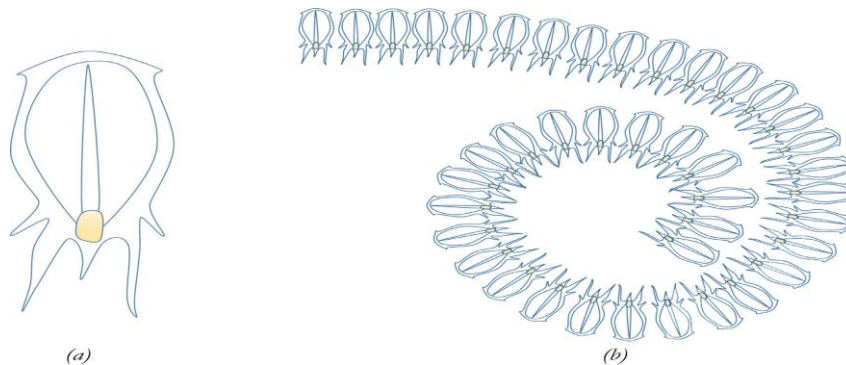


Figure 2: (a) One salp, (b) salps in the form of swarm (salp chain)[17]

In the purpose of mathematically modelling of SCH, Initially, the population should be split into two groups: The salp that is at the front of the chain and that guides the swarm is the leader, whereas the remains salps dealt as followers. They follow each other by the leader's guidance.

In the same of swarm-based techniques, the site of salps is specified in a search space with n -dimension where n represents all variables of the defined problem, then, the location of all salps are kept in a matrix with two-dimension named x , a food source called F is presumed as swarms target in search space.

The proposed equation of update the leader's site as follows [17]:

$$X_k^1 = \begin{cases} F_k + C_1((ub_k - lb_k)C_2 + lb_k) & C_3 \geq 0.5 \\ F_k - C_1((ub_k - lb_k)C_2 + lb_k) & C_3 < 0.5 \end{cases} \quad (18)$$

Where: X_k^1 is represents the leader (first salp) site in the k^{th} dimension, F_k is the food source site in the k^{th} dimension, ub_k point out to the upper bound of k^{th} dimension, while, lb_k point out to the lower bound of k^{th} dimension, C_2 and C_3 parameters are random numbers generated in a uniform manner in the interval $[0,1]$.

In the Eq. (18) the leader (first salp) only updates its site with respect to the food source (F_k). C_1 is the coefficient of exploration and exploitation, which can be determined according to the following equation [17]:

$$C_1 = 2e^{-\left(\frac{4l}{L}\right)^2} \quad (19)$$

Where l is the present iteration, and L is the maximum, number, of iterations. By utilization of newton's law of motion to update the follower's site by the following equation [17]:

$$X_k^i = \frac{1}{2}at^2 + v_0t \quad (20)$$

Where: $i \geq 2$, X_k^i is the site of i^{th} follower salp in k^{th} dimension, t is time, v_0 represent the initial speed; a is defined by $\frac{v_{final}}{v_0}$ where $v_{final} = \frac{x-x_0}{t}$.

As time in the optimization process is iteration, and v_0 assumed to be zero, the Eq. (20) can be rewritten as follows [17]:

$$X_k^i = \frac{1}{2} (X_k^i + X_k^{i-1}) \quad (21)$$

Where: $i \geq 2$, X_k^i is the site of i^{th} follower salp in the k^{th} dimension with Eq. (18) and Eq. (21) simulation of the salp chains can be done. The flowchart of the proposed salp swarm algorithm is shown in Figure 3.

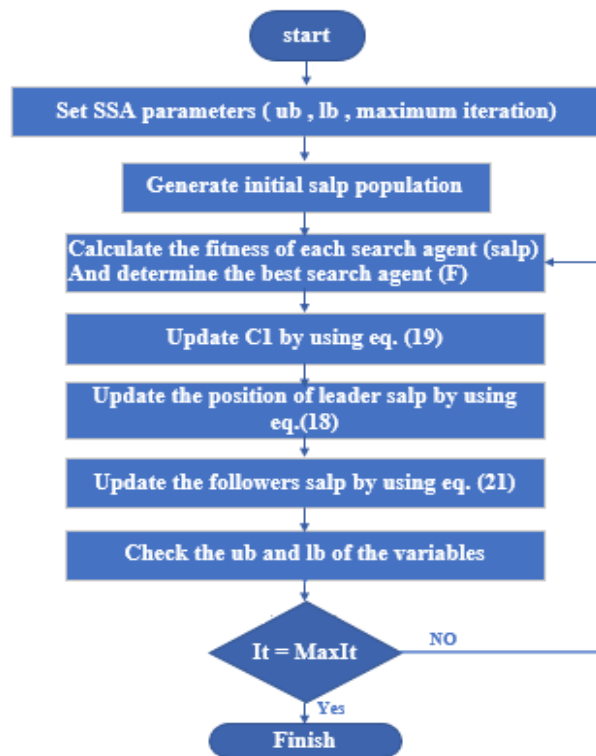


Figure 3: Flowchart of SSA [18]

I. Implementation of SSA to resolve the optimization problem

The steps to implement SSA as follows [19]:

Step (1): initiate the search agents considering the upper and lower bounds mentioned in section 2.4, the maximum number of iterations, and the total number of variables that yield the open switches numbers, sizes, and locations of DGs. For the only reconfiguration, the solution set is formulated as follows:

$$X = \begin{bmatrix} S_1^1 & S_2^1 & S_3^1 & S_4^1 & S_5^1 \\ S_1^2 & S_2^2 & S_3^2 & S_4^2 & S_5^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ S_1^n & S_2^n & S_3^n & S_4^n & S_5^n \end{bmatrix} \quad (22)$$

For only DG insertion, the solution set is formulated as follows:

$$X = \begin{bmatrix} L_1^1 & L_2^1 & L_3^1 & DG_1^1 & DG_2^1 & DG_3^1 \\ L_1^2 & L_2^2 & L_3^2 & DG_1^2 & DG_2^2 & DG_3^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ L_1^n & L_2^n & L_3^n & DG_1^n & DG_2^n & DG_3^n \end{bmatrix} \quad (23)$$

For both reconfiguration and DG insertion, the solution set is formulated as follows:

$$X = \begin{bmatrix} S_1^1 & S_2^1 & S_3^1 & S_4^1 & S_5^1 & L_1^1 & L_2^1 & L_3^1 & DG_1^1 & DG_2^1 & DG_3^1 \\ S_1^2 & S_2^2 & S_3^2 & S_4^2 & S_5^2 & L_1^2 & L_2^2 & L_3^2 & DG_1^2 & DG_2^2 & DG_3^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ S_1^n & S_2^n & S_3^n & S_4^n & S_5^n & L_1^n & L_2^n & L_3^n & DG_1^n & DG_2^n & DG_3^n \end{bmatrix} \quad (24)$$

Where: S indicates to switch, L and DG are indicates to location and size of DG .

Step (2): input the system data, which consists of a line and bus data, then using program of load flow study to compute the load flow of the whole system.

Step (3): by the load flow program, compute the power loss of every search agent Created. Estimate the fitness value by Eq. (7). Compute the leader site or best salp (search agent) using Eq. (18) for the iteration number one.

Step (4): update the parameter $C1$ by Eq. (19).

Step (5): update the site of leader or best search agent by Eq. (18) for every iteration.

Step (6): update the site of follower salp by Eq. (21) for every iteration.

Step (7): set the variables of search agent constrained by the lower and upper bounds, and then, compute the best fitness value (MOV).

Step (8): inspect the criterion of stopping. If $yes(i = i_{max})$, print the fitness value (MOV) and the corresponding solution set (open switches, locations, and sizes of DGs), otherwise, reiterate the steps 2 to 7.

4. SIMULATION RESULTS AND DISCUSSION

In this work, four cases are implemented on both test system IEEE 33-bus and AL-Fuhood distribution systems, which are:

Case 1: base case without reconfiguration and DG units' insertion.

Case 2: only optimum reconfiguration.

Case 3: only optimum DG units' insertion in the distribution systems.

Case 4: OSDGIR.

The parameters set of proposed SSA are listed in Table I. These parameters considered the same for both test and local Iraqi distribution systems.

TABLE I: Parameters of SSA

Parameter	Value
Maximum iteration	50
Initial population	30

I. Test system

The test system is an IEEE 33-bus radial distribution system with a real power demand of 3,715 KW and reactive power demand of 2,300 Kvar. There are 32 sectionalizing switches in addition to 5 tie lines existing in this system, as shown in Figure 4. Usually, the sectionalizing switches from 1 to 32 are closed, while the five tie lines switches from 33 to 37 are opened.

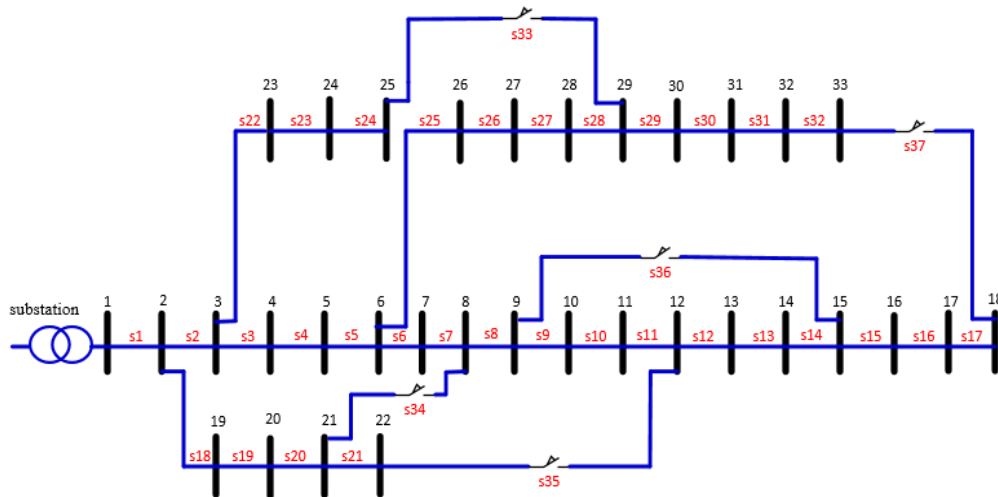


Figure 4: IEEE 33 bus radial distribution system diagram [4]

TABLE II: Simulation results of SSA on 33-bus radial test system

case	Power loss (KW)	Min voltage in p.u (bus No.)	RVI (%)	DG size in MW (bus No.)	Opened switches	Loss reduction (%)
Case 1	202.67	0.913 (18)	---	---	33,34,35,3,6,37	---
Case 2	135.77	0.936 (33)	2.74	---	8,34,33,13,29	33
Case 3	27.89	0.967 (18)	4.4	1.0 (23), 1.0 (30), 1.0 (7)	---	86.23
Case 4	14	0.99 (33)	5.4	1.0 (23), 1.0 (30), 1.0 (7)	15,33,34,1,2,35	93.1

It is observed from Table II, that total PL of base case is 202.67 KW, which is minimized to 135.77,27.89, and 14 after implementation the cases 2,3, and 4, respectively, the minimum voltage is improved from 0.913 (base case) to 0.936,0.967,0.99 after execution the three cases from 2 to 4. The RVI is enhanced to 2.74%, 4.4%, 5.4% after applying the cases 2 to 4, respectively. It is noticed the real PL reduction is accomplished: 33% (only reconfiguration), 86.23% (only DG units allocations), and 93.1% (OSDGIR). It is cleared than all the results obtained by applying the case 4 are the best compared to other cases.

Figures 5-6, illustrate the comparison of three cases 2,3, and 4 compared with the base case in terms of VP and reduced PL, it is cleared that results obtained by case 4 is better than other cases. from Figure 5, it is noticed a significant improvement of voltage profile after applying the cases 2, 3, and 4, where case 4 gave the best results among the others.

The optimum topology of DS after OSDGIR by SSA is illustrated in Figure 7.

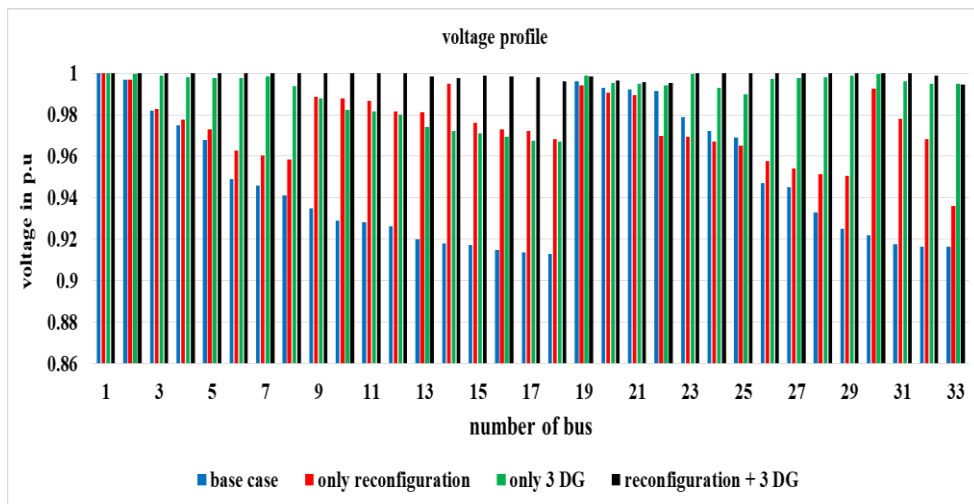


Figure 5: Voltage profile of four cases

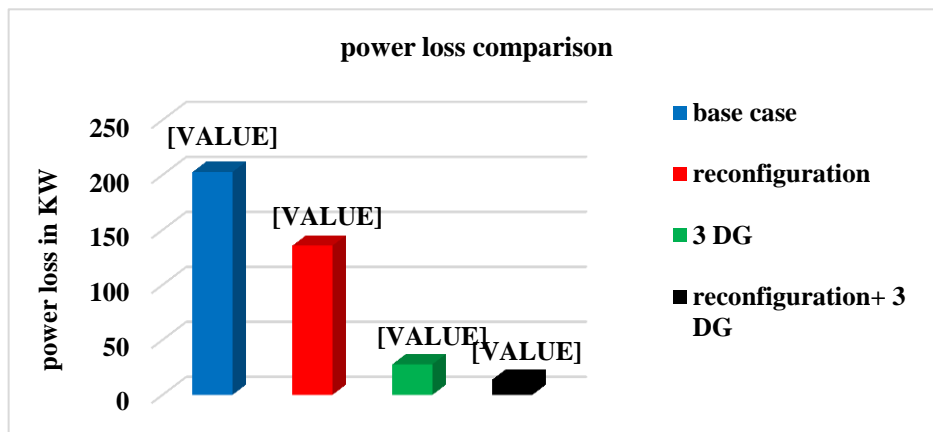


Figure 6: Simulation of PL comparison

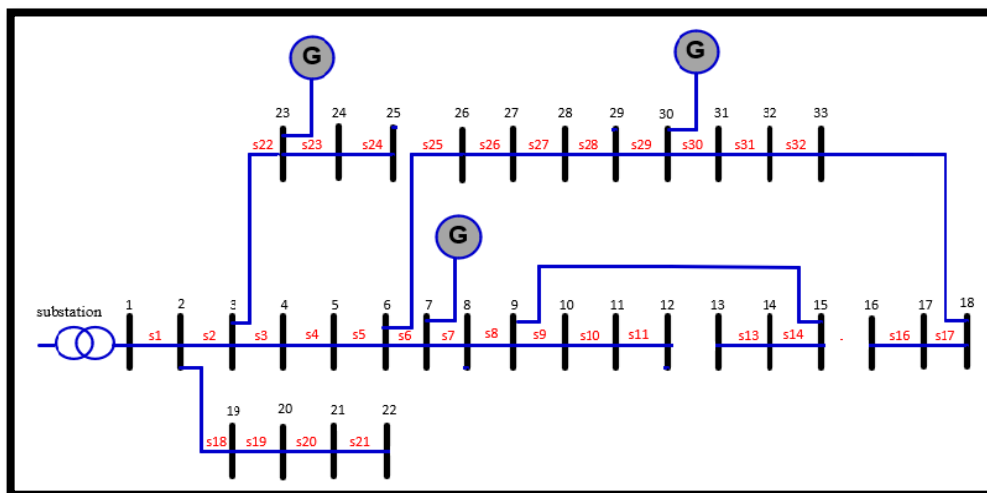


Figure 7: Optimum topology of DS after OSDGIR

To establish the effectiveness of the proposed (SSA) approach, the results obtained are compared with those obtained by [12], and [14]. It is regarded from Table III that the results of all three cases by proposed method (SSA) are superior to those obtained by HSA and CTLHSO with regard to PL and VD reduction.

TABLE III: Comparison of SSA results for 33- bus test system

Cases	Entity	HSA [12]	CTLHSO [14]	Proposed SSA
Case 2	Power loss (KW)	138.6	139.55	135.77
	Min voltage in p.u (bus No.)	0.934	0.937	0.9367 (33)
	Opened switches	7,14,9,32,37	7,9,14,32,37	8,34,33,13,29
	Loss reduction (%)	31.88	31.14	33
	Power loss (KW)	96.76	71.46	27.89
Case 3	Min voltage in p.u (bus No.)	0.967	0.968	0.967 (18)
	Sizes of DG units in MW (bus No.)	0.107 (18)	0.754 (14)	1.0 (7)
		0.5724 (17)	1.099 (24)	1.0 (23)
		1.0462 (33)	1.071 (30)	1.0 (30)
	Loss reduction (%)	52.26	64.74	86.23
Case 4	Power loss (KW)	73.05	50.72	14.0
	Min voltage in p.u (bus No.)	0.97	0.9734	0.99 (33)
	Opened switches	7,14,10,32,28	11,28,31,33,34	15,33,34,12,35
	Sizes of DG units in MW	0.5258 (32)	0.9569 (7)	(23)
	(bus No.)	0.5586 (31)	0.7230 (17)	(30)
	0.5840 (33)	1.2796 (25)	1.0 (7)	
	Loss reduction (%)	63.95	74.97	93.1

II. AL-Fuhood distribution network

AL-Fuhood district is in the south of the city of Thi-Qar, about 65 KM, the feed own secondary power station consist of 12 feeders, one of them to feed a rural area (the farms feeder) which considered among the worst cases in terms of the voltage stability and power losses, and for this reason, have been selected. The network is illustrated in Figure 8, the rated voltage is 11.5 kV, and it consists of 33-bus.

The data of network (bus data, line data) as listed in appendix (A), where the total peak loads are 7360 KW (7.36 MW) depending on the ratings of transformers at buses, after divide it on diversity factor of 1.25 will be 5888 KW (5.888 MW). There are no tie lines in the network in practical, so in order to implement the reconfiguration process, the tie lines are assumed as listed in appendix (A). It is noticed from Table IV that the total real PL of AL-FUHOOD distribution network base case is 441.06 KW, after applying the cases 2, 3, and 4, it minimized to 363.7, 100.178, and 93.62, respectively.

The minimum voltage of base is 0.898 p.u, which is under allowable limits of voltage (less than 0.9 p.u) improved to 0.923,0.965,0.9867 after the execution of the three cases from 2 to 4, respectively, all these values are above 0.9 p.u, a boost of RVI is achieved to 1.6%, 6.6%, 8.2% after applying the cases 2 to 4, respectively, the average voltage is enhanced from 0.898 (case 1) to 0.937 (case 2), 0.9828 (case 3), and 0.9867 (case 4).

TABLE IV:Simulation results of SSA on 33 bus radial AL-Fuhood distribution network

case	Power loss (KW)	Min voltage in p.u (bus No)	RVI (%)	DG size in MW (bus No)	Opened switches	Loss reduction (%)
Base	441.06	0.898 (26)	---	---	33,34,35,36,37	---
Case 2	363.7	0.923 (25)	1.6	---	18,24,36,34,22	17.54
Case 3	100.178	0.965 (26)	6.6	1.278 (27)	---	77.28
				1.6237 (3)		
				1.8274 (28)		
Case 4	93.6218	0.9867 (26)	8.2	3.0 (8)	23,19,22,21,31	78.77
				1.0 (11)		
				1.0 (1)		

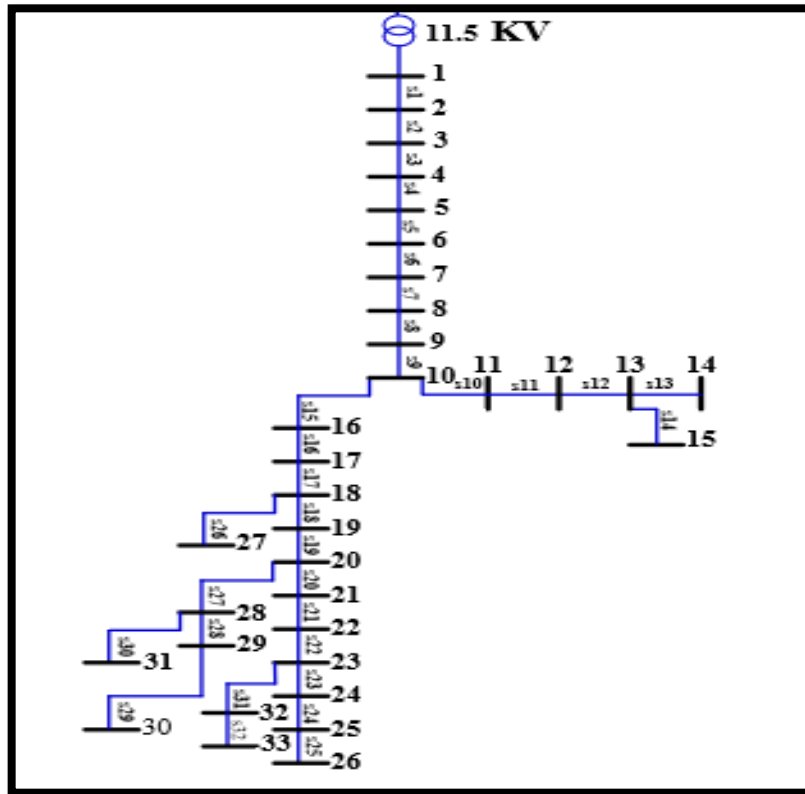


Figure 8: AL-Fuhood distribution network

Also, it is observed that PL reduction is fulfilled: 17.54% (case 2), 77.28% (case 3), and 78.77% (case 3). The results obtained from the fourth case are much better than the other three. Figure 9-10, clarify the comparison of four cases in terms of improved VP and reduced real PL. The results obtained by case 4 is better than in other cases. From Figure 9, it is observed a notable enhancement of VP after applying the cases 2, 3, and 4, where case 4 gave the best results among the others.

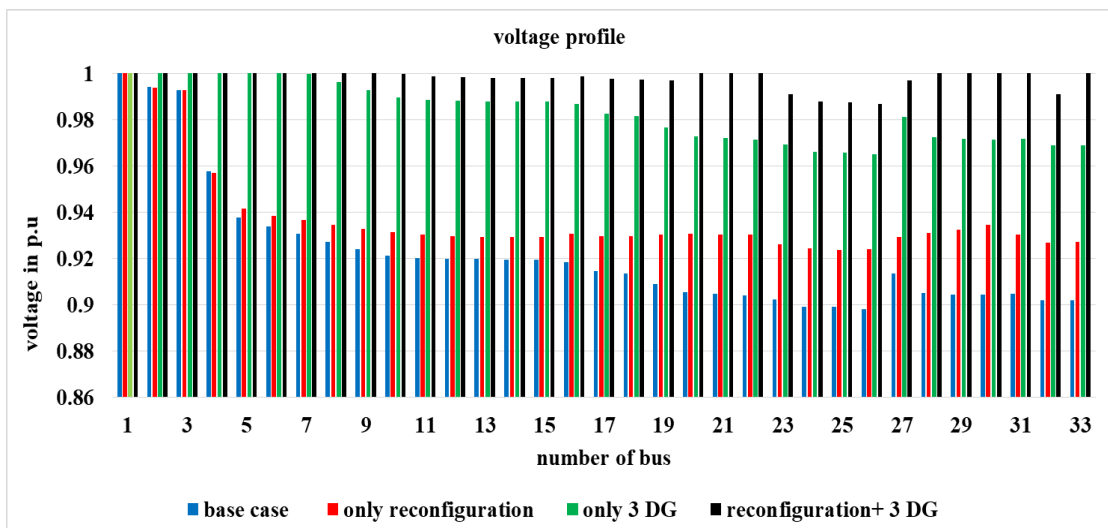


Figure 9: Voltage profile of four cases

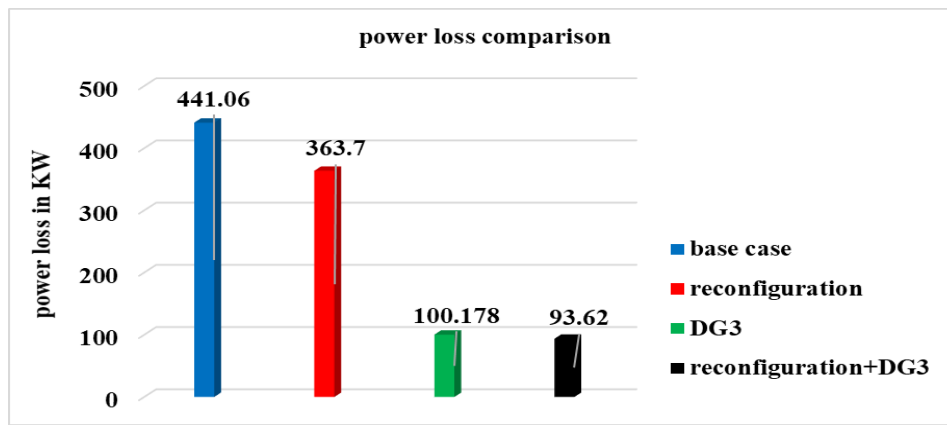


Figure 10: power loss comparison of four cases

5. CONCLUSION

In this paper, three various techniques (only reconfiguration, only DG units’ insertion, and Optimum simultaneous Reconfiguration and DG units insertion) are applied on IEEE 33-bus and 33-bus local Iraqi distribution network (AL-Fuhood distribution network) for reduce the line loss and improve voltage profile of two systems. Considerable minimization in power loss and voltage deviation is achieved after applying the three techniques on both systems. Among the three techniques, the technique 3 gave the best results in term of minimized power loss, enhanced recovery voltage index, and boosted minimum voltage.

It is observed that the recovery voltage index enormously enhanced by 5.4%, and 8.2%, PL extremely minimized by 93.1% and 78.77%, average voltage boosted to 0.999 p.u and 0.997 p.u. Minimum voltage upgraded to 0.998 p.u and 0.9867 p.u after applying the optimum simultaneous DG units insertion and distribution network reconfiguration on both test system and AL-Fuhood distribution network, respectively. The proposed method SSA proved its superiority when the results obtained from the test system are compared with used HSA and CTLHSO methods in ref.[12] and ref.[14].

Appendix-1

I Bus data of the AL-Fuhood network

Bus No.	P-load (MW)	Q-load (Mvar)	Bus No.	P-load (MW)	Q-load (Mvar)
2	0.200	0.150	18	0.320	0.240
3	0.200	0.150	19	0.200	0.1500
4	0.200	0.150	20	0.200	0.150
5	0.200	0.150	21	0.200	0.150
6	0.200	0.150	22	0.200	0.150
7	0.320	0.240	23	0.320	0.240
8	0.200	0.150	24	0.320	0.240
9	0.320	0.240	25	0.080	0.060
10	0.200	0.150	26	0.200	0.1500
11	0.320	0.240	27	0.320	0.240
12	0.320	0.240	28	0.200	0.150
13	0.320	0.240	29	0.200	0.150
14	0.200	0.150	30	0.200	0.150
15	0.200	0.150	31	0.200	0.150
16	0.200	0.150	32	0.200	0.150
17	0.200	0.150	33	0.200	0.150

line data of AL-Fuhood distribution network

Sending bus	Receiving bus	R (Ω)	X (Ω)	Length (meter)
1	2	0.07125	0.08697	300
2	3	0.01425	0.01739	60
3	4	0.4512	0.5508	1900
4	5	0.2612	0.3188	1100
5	6	0.0456	0.0666	230
6	7	0.0475	0.0579	200
7	8	0.0475	0.0579	200
8	9	0.0475	0.0579	200
9	10	0.0475	0.0579	200
10	11	0.0593	0.0724	250
11	12	0.0356	0.0434	150
12	13	0.0237	0.0289	100
13	14	0.0475	0.0579	200
13	15	0.0712	0.0869	300
10	16	0.0593	0.0724	250
16	17	0.095	0.1159	400
17	18	0.0237	0.0289	100
18	19	0.1425	0.1739	600
19	20	0.1187	0.1449	500
20	21	0.0237	0.0289	100
21	22	0.0475	0.0579	200
22	23	0.1187	0.1449	500
23	24	0.475	0.5798	2000
24	25	0.0712	0.0869	300
25	26	0.3325	0.4058	1400
18	27	0.0712	0.0869	300
20	28	0.0356	0.0434	150
28	29	0.1187	0.1449	500
29	30	0.1187	0.1449	500
28	31	0.1900	0.2319	800
23	32	0.1187	0.1449	500
32	33	0.0237	0.0289	100
Assumed tie lines				
14	26	1.615	1.9713	6800
16	22	0.4512	0.5508	1900
4	30	1.2184	1.4872	5130
10	23	0.6294	0.7682	2650
6	33	0.9619	1.1741	4050
Assumed tie lines switches				
No switch		From bus		To bus
S33		14		26
S34		16		22
S35		4		30
S36		10		23

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