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Oppositional krill herd algorithm for optimal location of capacitor with reconfiguration in radial distribution system

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ABSTRACT

The delivery of power from sources to the consumer points is always accompanied of power losses. Basically, active losses in distribution systems can be reduced by optimal reconfigurations of the network. Optimal capacitor allocation problem in reconfigured distribution network is a challenge of researchers for several decades. This paper presents a computationally efficient methodology namely, krill herd (KH) algorithm to find optimal location of capacitor and optimal reconfiguration in order to minimize real power loss of radial distribution systems. Moreover, the opposition based learning (OBL) concept is integrated with KH algorithm for improving the convergence speed and simulation results. In order to show the usefulness and supremacy, the conventional KH and proposed oppositional KH (OKH) algorithms are tested on 33-bus and 69-bus radial distribution networks. The simulation results of the proposed methods are compared with fuzzy multi-objective approach and non dominated sorting genetic algorithm (NSGA). The solution results show that OKH technique could generate better quality solutions and better convergence characteristics than those obtained by conventional KH algorithm and other existing optimization techniques available in the literature. Results also show the robustness of the proposed methodology to solve reconfigured distribution network (RDN) problems.

Introduction

Reactive power compensation is an important topic of research to achieve power and energy loss reduction, system capacity release and acceptable voltage profile. There are many alternatives available for reducing losses at the distribution level: reconfiguration, capacitor installation, load balancing and introduction of higher voltage levels. This research focuses on the reconfiguration and capacitor installation on the radial distribution network. Over the past few years, many research work have been carried out to find optimal placement and size of capacitors when they are required to be installed in the system by using different optimization techniques such as classical methods [1–3], mixed integer linear programming (MILP) [4], hybrid simulated annealing (HSA) [5], particle swarm optimization (PSO) [6], genetic algorithm (GA) [7,8], and biogeography based optimization (BBO) [9].

In recent years, the load demand in distribution systems is sharply increasing due to economical and environmental pressures. Moreover, with the advent of deregulation in the power industry, there is a greater focus on managing network assets efficiently rather than reinforcing the network's capacity. Feeder reconfiguration would allow for the transfer of load from heavily loaded portions of the network to relatively lightly loaded portions of the system. So, reconfiguration and capacitor allocation procedures in radial electrical distribution systems are attractive alternatives for technical losses reduction [10,11]. In addressing this problem, the main objective of this article is to find the best radial topology in order to obtain minimum power losses, meet the energy demand and maintain system reliability. The reconfiguration of a distribution system is a process, which alters the feeder topological structure by changing the open/close status of the sectionalizing (normally closed) and the tie switches (normally open) in the system.

In this study, the authors have done survey for reconfiguration of distribution system network. Franscisco et al. proposed MILP [12] for determining the active power loss of balanced large-scale distribution system. Franco et al. used MILP model [13] of reconfiguration of distribution systems considering the presence of distributed generation (DG). Pfitscher et al. presented analytic hierarchic process (AHP) method [14] to determine the best sequence of switching of distribution network for reconfiguration of the network. Milani et al. proposed probabilistic approach [15] to perform an optimal reconfiguration in order to reduce the total cost of operation, including the cost of switching and benefit

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of loss reduction. Lopez et al. introduced an efficient online evaluation technique [16] for solving distribution feeder reconfiguration problem. Khodr et al. suggested optimal power flow (OPF) based on benders decomposition approach [17] for loss reduction as well as the load balancing among the feeder. Oliveira et al. used mixed integer non linear programming (MINLP) [18] for reconfiguration under the presence of capacitor allocation to minimize energy losses on radial electrical networks considering different load levels. The Lagrange multipliers were used to evaluate sensitivity index for distribution reconfiguration.

There are many techniques which are based on stochastic searches, so as to get a faster convergence rate. However, this advantage also leads to a higher probability of obtaining local optimums. To overcome this drawback, various hybrid versions were proposed by the researchers. Song et al. proposed fuzzy controlled evolutionary programming (Fuzzy EP) [19] to reconfigure distribution network to reduce system power loss. Venkatesh et al. proposed fuzzy adoption of EP [20] for reconfiguration. However, this method requires several iterations resulting in considerably high computational time. Niknam et al. introduced a hybrid evolutionary algorithm based on the combination of honey bee mating optimization (HBMO) and discrete PSO (DPSO) [21] for multi-objective distribution feeder reconfiguration. Chiou et al. presented a method based on variable scaling hybrid differential evolution (VSHDE) [22] for solving the network reconfiguration for power loss reduction and voltage profile enhancement of distribution systems and also a mixed integer HDE (MIHDE) [23] was proposed for reconfiguration of distribution network. Ahuja et al. suggested a hybrid algorithm based on ant colony optimization (ACO) and artificial immune systems (AIS) [24] to solve distribution feeder reconfiguration. A fuzzy genetic based approach [25] was presented by Sahoo et al. for reconfiguration of radial distribution systems to maximize the voltage stability for a specific set of loads. Niknam et al. proposed a hybrid algorithm based on HBMO and fuzzy set [26] for the multi-objective distribution feeder reconfiguration. Das et a. used fuzzy multi-objective approach [27] that attempted to minimize the number of tie switch operation based on the heuristic rules and for each tie-switch operation, it

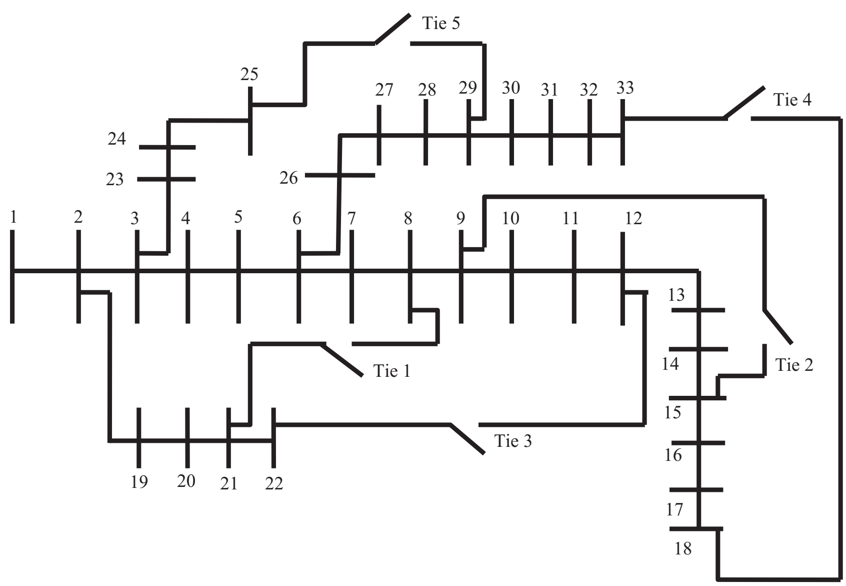

Fig. 1. Single line diagram of 33-bus radial distribution system.

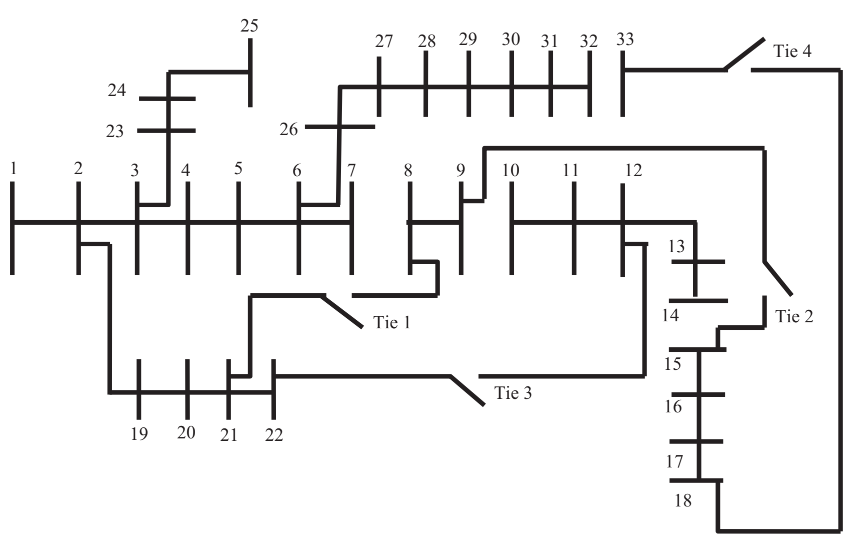

Fig. 2. The configuration diagram of 33-bus radial distribution system for constant power type load for load multiplying factor of 1.0.

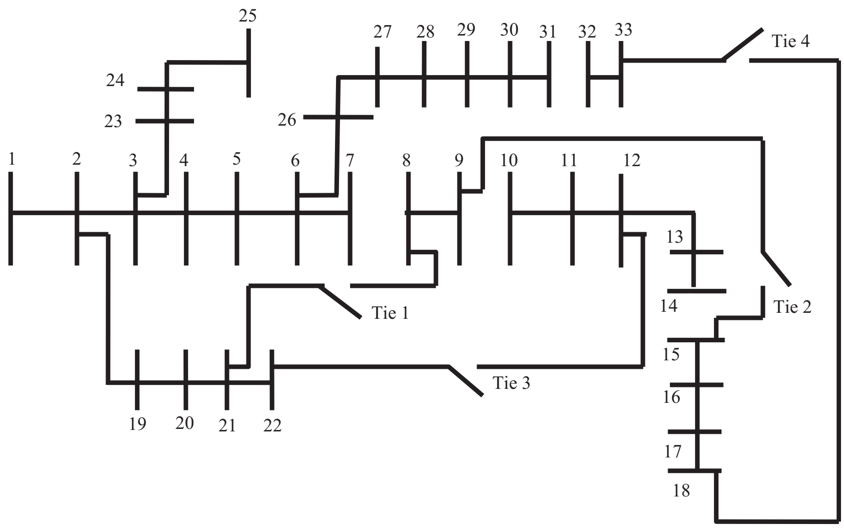

Fig. 3. The configuration diagram of 33-bus radial distribution system for constant current type load for load multiplying factor of 1.0.

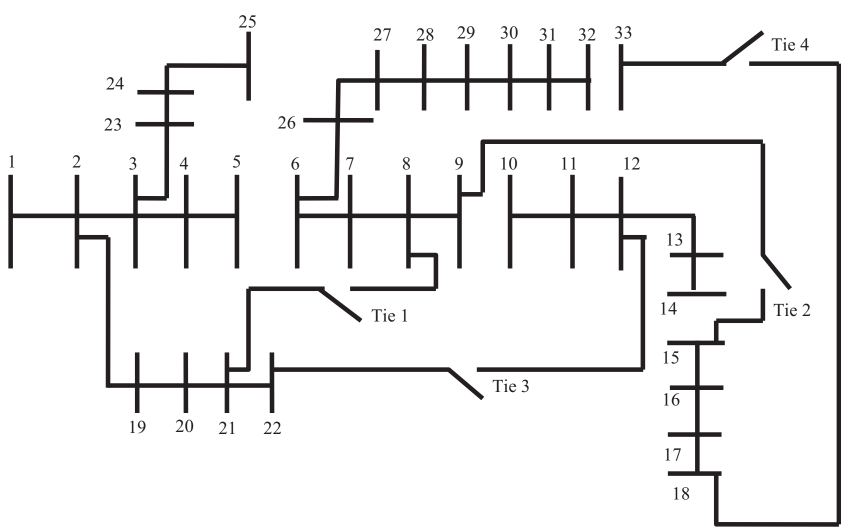

Fig. 4. The configuration diagram of 33-bus radial distribution system for constant impedance type load for load multiplying factor of 1.0.

Table 1
Results of 33-bus system before after reconfiguration for constant power type load for load multiplying factor of 1.0.

Status of reconfiguration	Without reconfiguration			With reconfiguration				
	Without capacitor placement	With capacitor placement		Without capacitor placement			With capacitor placement	
		KH	OKH	NSGA [44]	KH	OKH	KH	OKH
Power loss (kW)	210.998	154.5695	153.7981	129.7	127.6838	115.0892	115.6237	114.2278
Optimal position of capacitor	NA	30	62	NA	NA	NA	27	27
Optimal size of capacitor	NA	95.8917	99.7147	NA	NA	NA	85.6557	99.7137
Opening branches	NA	NA	NA	7–8	7–8	7–8	7–8	7–8
				9–10	9–10	9–10	9–10	9–10
				14–15	14–15	14–15	14–15	14–15
				32–33	31–32	32–33	32–33	32–33
Closing branches	NA	NA	NA	21–8	21–8	21–8	21–8	50–59
				9–15	9–15	9–15	9–15	27–65
				22–12	22–12	22–12	22–12	15–46
				18–33	18–33	18–33	18–33	18–33
Min. voltage	0.9038	0.9137	0.9140	0.9450	0.9410	0.9493	0.9437	0.9438
Voltage stability index	0.6672	0.6969	0.6980	0.7976	0.7858	0.8122	0.7933	0.7934

Table 2
Results of 33-bus system before after reconfiguration for constant current type load for load multiplying factor of 1.0.

Status of reconfiguration	Without reconfiguration			With reconfiguration	
	Without capacitor placement	With capacitor placement		With capacitor placement	
		KH	OKH	KH	OKH
Power loss (kW)	182.1760	144.4833	138.8991	101.5678	98.1917
Optimal position of capacitor	NA	28	29	28	27
Optimal size of capacitor	NA	90.2274	99.6274	95.2492	99.3492
Opening branches	NA	NA	NA	7–8 9–10 14–15 31–32	7–8 9–10 14–15 31–32
Closing branches	NA	NA	NA	21–8 9–15 22–12 18–33	21–8 9–15 22–12 18–33
Min. voltage	0.9115	0.9195	0.9204	0.9411	0.9411
Voltage stability index	0.6903	0.7149	0.7176	0.7860	0.7860

Table 3
Results of 33-bus system before after reconfiguration for constant impedance type load for load multiplying factor of 1.0.

Status of reconfiguration	Without reconfiguration			With reconfiguration	
	Without capacitor placement	With capacitor placement		With capacitor placement	
		KH	OKH	KH	OKH
Power loss (kW)	160.7273	127.4430	124.0021	116.7926	107.3133
Optimal position of capacitor	NA	31	30	6	6
Optimal size of capacitor	NA	88.1530	97.9238	41.2304	98.2864
Opening branches	NA	NA	NA	5–6 9–10 14–15 32–33	5–6 9–10 14–15 32–33
Closing branches	NA	NA	NA	8–21 12–22 9–15 18–33	8–21 12–22 9–15 18–33
Min. voltage	0.9176	0.9247	0.9254	0.9238	0.9446
Voltage stability index	0.7090	0.7310	0.7335	0.7282	0.7959

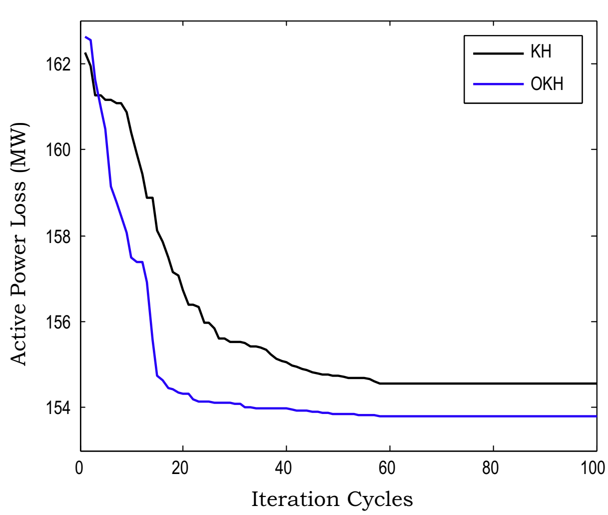

Fig. 5. Loss convergence using KH and OKH of 33-bus system without reconfiguration for constant power load for load multiplying factor of 1.0.

maximized the fuzzy satisfaction objective function for obtaining optimum configuration. Bernardon et al. proposed fuzzy multi criteria decision making algorithm [28] for the proper processing of the information sources available at the utilities in the context of distribution network reconfiguration. Arun et al. presented a fuzzy based reconfiguration algorithm [29] on 69-bus distribution system to enhance voltage stability and improves voltage profile without incurring any additional cost for installation of capacitors, tap changing transformers and related switching equipments in the distribution system. Banerjee et al. introduced an algorithm for reconfiguration of radial distribution networks based on fuzzy multi-objective approach [30] by considering different types of loads. Wagner et al. proposed a linear programming method using transportation techniques and a heuristic search method [31] for feeder reconfiguration with loss reduction as objective. Ahmed et al. developed a load flow program which was integrated with heuristic techniques in a new heuristic search methodology [32] for determining the minimum loss configuration of radial distribution system. To demonstrate the validity of the proposed algorithm, it was applied on 33-bus system. Results showed that it gave better results than that of other methods. A two-stage solution methodology based on a modified simulated annealing technique (MSA) [33] used for solving reconfiguration problem of distribution systems and used for loss reduction of distribution network was proposed by Chang et al. [34]. The SA algorithm with tabu search (TS) was incorporated in [35] for loss reduction by Jeon et al. The TS attempted to determine a better solution in the manner of a greatest-descent algorithm but it could not give any guarantee for the convergence property. A parallel TS (PTS) [36] based method was proposed for feeder reconfiguration by Mori et al. and TS algorithm was presented [37] for solving the problem of network reconfiguration in distribution systems in order to reduce the resistive line losses under normal operating conditions. Zhang et al. presented an improved TS (ITS) algorithm [38] for loss-minimization reconfiguration in large-scale distribution systems. A modified TS (MTS) [39,40] based algorithm was used for reconfiguration of distribution systems using turning on/off sectionalizing switches to minimize active power losses. A number of artificial intelligent methods such as, GA [41,42], adaptive GA (AGA) [43] were proposed to reconfigure distribution feeders with the objective of minimizing real power losses while avoiding transformer and feeder overloads and inadequate voltages. Chandramohan et al. used non-dominated sorting GA (NSGA) [44] for reconfiguring to minimize its operating costs considering the system real power loss and the cost of reactive power purchased by the distribution system. Another approach for reconfiguration with capacitor allocation is proposed [45] by using ant colony search (ACS) algorithm, in order to reduce active power losses. Bacterial foraging optimization algorithm (BFOA) used [46] for distribution network reconfiguration with the objective of loss minimization was proposed by Kumar et al.

From the literature survey, it may be concluded that conventional techniques like MILP, OPF, MINLP etc., required more computation time and are less robust. Moreover, most of the artificial

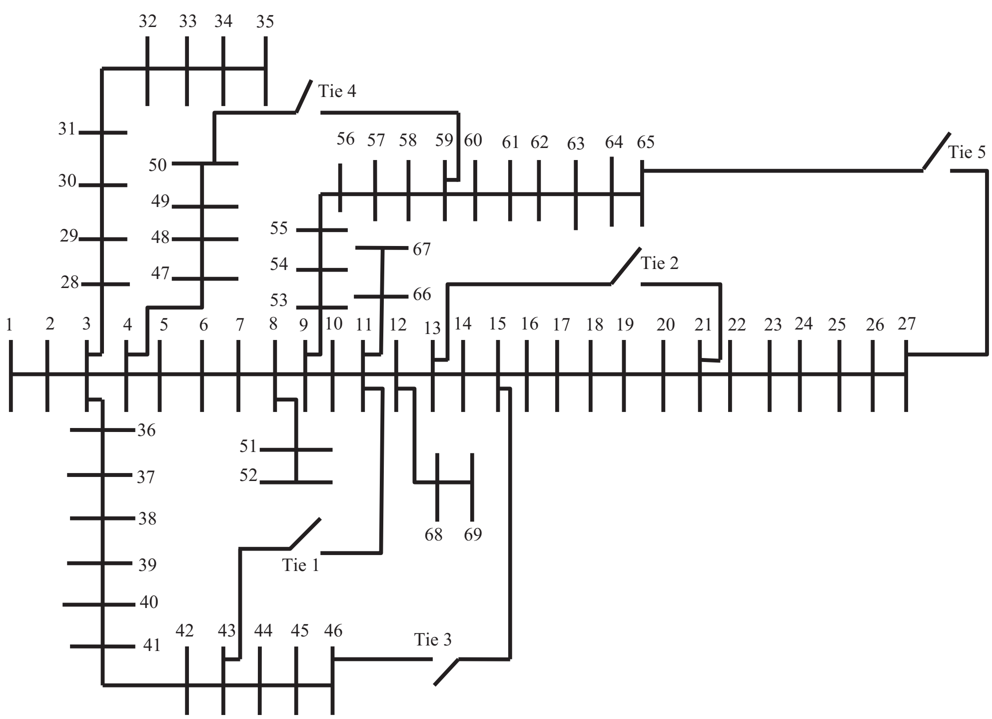

Fig. 6. Single line diagram of 69-bus radial distribution system.

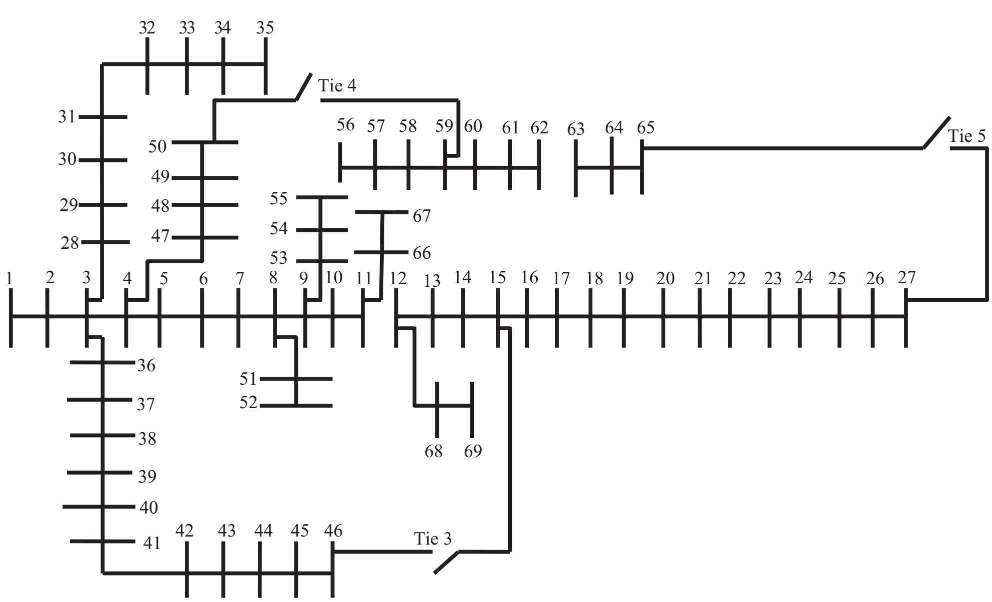

Fig. 7. The configuration diagram of 69-bus radial distribution system for constant power type load for load multiplying factor of 1.0 and 1.5, composite type load for load multiplying factor of 1.5.

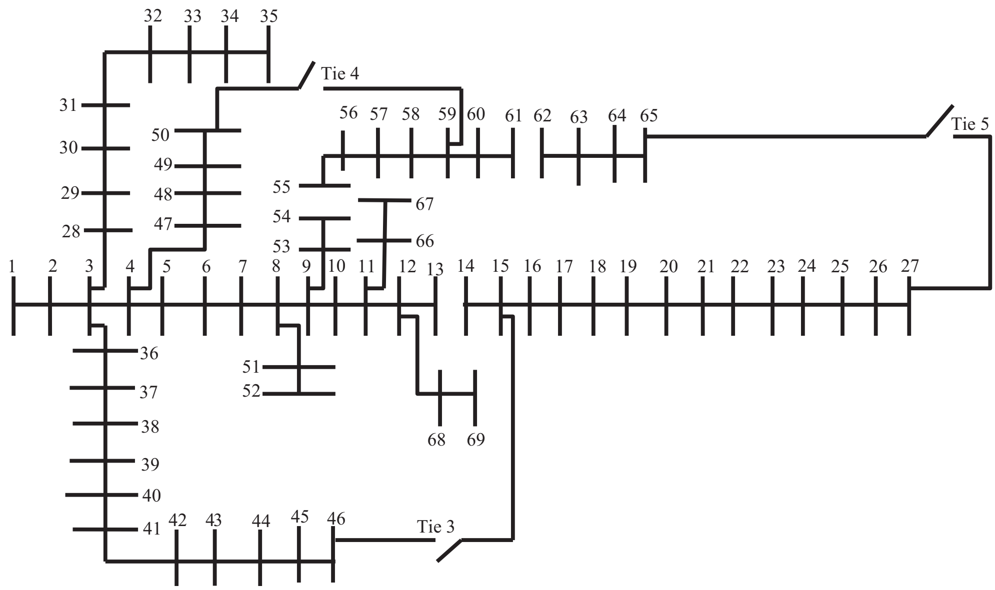

Fig. 8. The configuration diagram of 69-bus radial distribution system for constant current type and composite type load for load multiplying factor of 1.0 and constant current type and constant impedance type load for load multiplying factor of 1.5.

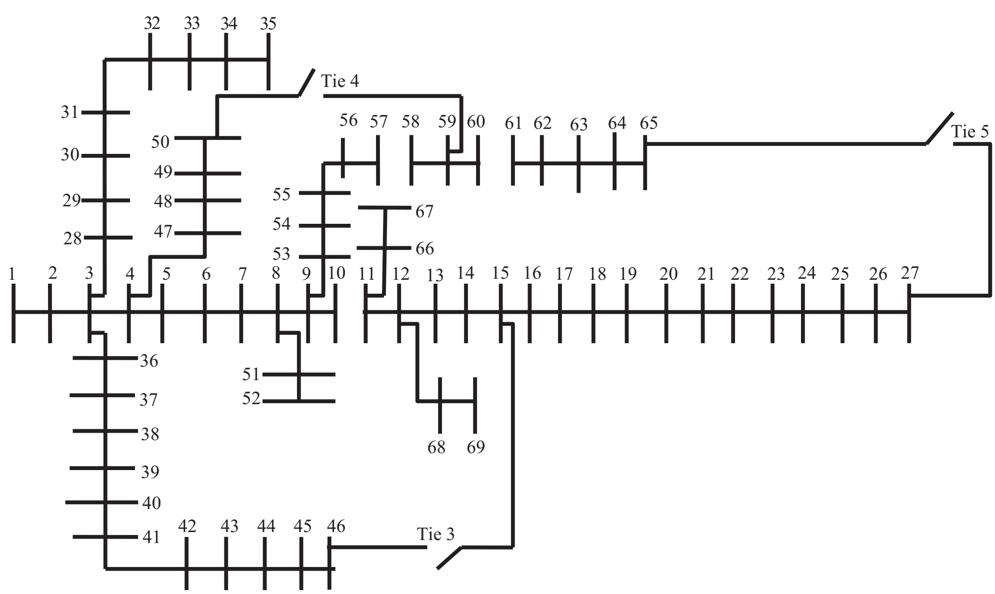

Fig. 9. The configuration diagram of 69-bus radial distribution system for constant impedance type load for load multiplying factor of 1.0.

Table 4
Results of 69-bus system before after reconfiguration for constant power type load for load multiplying factor of 1.0.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	With capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	224.2	186.6	160.3947	157.4568	95.1	69.4384	67.6531
Optimal position of capacitor	NA	61	62	62	61	58	59
Optimal size of capacitor	NA	400	88.0041	97.4097	400	92.0233	98.5233
Opening branches	NA	NA	NA	NA	57–58	55–56	55–56
					64–65	62–63	62–63
					12–13	11–12	11–12
Closing branches	NA	NA	NA	NA	50–59	50–59	50–59
					27–65	27–65	27–65
					15–46	15–46	15–46
Min. voltage	0.9095	0.9164	0.9241	0.9256	0.9450	0.9648	0.9648
Voltage stability index	0.6483	0.7051	0.7294	0.7341	0.7976	0.8651	0.8652

Table 5
Results of 69-bus system before after reconfiguration for constant current type load for load multiplying factor of 1.0.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	With capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	191.0	161.4	139.5468	137.4867	95.1	63.3249	61.4412
Optimal position of capacitor	NA	61	61	61	61	59	59
Optimal size of capacitor	NA	400	91.0487	99.9487	400	89.8787	94.1175
Opening branches	NA	NA	NA	NA	56–57	13–14	13–14
					64–65	54–55	54–55
					12–13	61–62	61–62
Closing branches	NA	NA	NA	NA	50–59	50–59	50–59
					27–65	27–65	27–65
					15–46	15–46	15–46
Min. voltage	0.9170	0.9227	0.9297	0.9300	0.9450	0.9674	0.9685
Voltage stability index	0.7070	0.7248	0.7460	0.7511	0.7976	0.8724	0.8766

Table 6
Results of 69-bus system before after reconfiguration for constant impedance type load for load multiplying factor of 1.0.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	With capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	166.8	142.5	124.0666	123.0470	79.9	34.8146	34.7554
Optimal position of capacitor	NA	61	61	61	61	26	20
Optimal size of capacitor	NA	400	91.0286	99.5876	400	59.9801	64.4441
Opening branches	NA	NA	NA	NA	57–58	10–11	10–11
					64–65	57–58	57–58
					12–13	60–61	60–61
Closing branches	NA	NA	NA	NA	50–59	50–59	50–59
					27–65	27–65	27–65
					15–46	15–46	15–46
Min. voltage	0.9228	0.9277	0.9344	0.9352	0.9500	0.9639	0.9634
Voltage stability index	0.7252	0.7408	0.7623	0.7649	0.8147	0.8629	0.8614

Table 7
Results of 69-bus system before after reconfiguration for composite type load for load multiplying factor of 1.0.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	Without capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	194.6	164.1	141.2469	139.8832	87.7	66.8178	61.3969
Optimal position of capacitor	NA	61	63	61	61	57	59
Optimal size of capacitor	NA	400	81.2383	98.1980	400	91.2559	99.6559
Opening branches	NA	NA	NA	NA	55–56	13–14	13–14
					64–65	54–55	54–55
					12–13	61–62	61–62
Closing branches	NA	NA	NA	NA	50–59	50–59	50–59
					27–65	27–65	27–65
					15–46	15–46	15–46
Min. voltage	0.9161	0.9220	0.9305	0.9301	0.9474	0.9680	0.9691
Voltage stability index	0.7044	0.7225	0.7497	0.7484	0.8057	0.8747	0.8780

intelligence based optimization techniques like GA, PSO, TS, SA, ACO, DE etc., are suffered from premature convergence. So, many publications used hybrid optimization techniques to obtain an efficient and reliable solution to the problem by adding their strengths and discarding the weakness. However, hybrid techniques suffer from the drawback of less robust, less computational efficiency when solve a large scale optimization problem. These motivated the present authors to introduce a new, efficient, simple and fast population based optimization technique to solve reconfiguration problem of radial distribution system with the placement of capacitor considering different types of loads.

In this study the author presented conventional krill herd (KH) algorithm to minimize power loss of distribution system. The main disadvantage of KH algorithm is lack of balancing capability between exploration and exploitation [47]. Furthermore, to speed up the search space and to improve the convergence rate, oppositional KH (OKH) is used. To show the effectiveness and superiority, the proposed methods are implemented on 33-bus and 69-bus distribution systems to minimize power loss and its simulation results are compared with other population based techniques.

The rest of the paper is organized as follows. In Section 'Mathe matical problem formulation', problem formulation with constraints of optimal DG allocation problem is discussed. The proposed KH method is briefly described in Section 'Krill herd algorithm'. The oppositional based learning (OBL) is briefly discussed in Section 'Opposition-based learning'. The algorithm steps of OKH applied to optimal capacitor placement problem of radial distribution system are explained in Section 'OKH algorithm applied to reconfiguration problem along with capacitor'. Simulation results and the comparative study are reported in Section 'Results and discussion'. Finally, conclusions are drawn in Section 'Conclusion'.

Mathematical problem formulation

It is observed from the literature that uncertain heavily loaded condition experiences huge losses in radial distribution system. In this article, optimal reconfiguration and optimal capacitor placement is made which helps to improve power loss and maintain bus voltage within a specified limit.

Objective function

Reconfiguration considering capacitor placement is mainly concerned with the minimization of real power loss. The real power loss formula may be defined as [48]:

$$P_{loss} = \sum_{m=1}^{N_B}\sum_{n=1}^{N_B}\frac{R_{m,n}}{V_mV_n}\cos(\delta_m-\delta_n)(P_mP_n+Q_mQ_n) + \frac{R_{m,n}}{V_mV_n}\sin(\delta_m-\delta_n)(Q_mP_n-P_mQ_n) \quad (1)$$

where $R_{m,n}$ is the resistance of the distribution line connected between the mth and the nth bus; $V_m,\ V_n$ are the bus voltages at the mth and the nth bus; N_B is the number of buses in the distribution network; $P_m,\ Q_m$ are net active and reactive power at the mth bus; $P_n,\ Q_n$ are net active and reactive power at the nth bus; $\delta_m,\ \delta_n$ are phase angles of voltages at the mth and the nth bus.

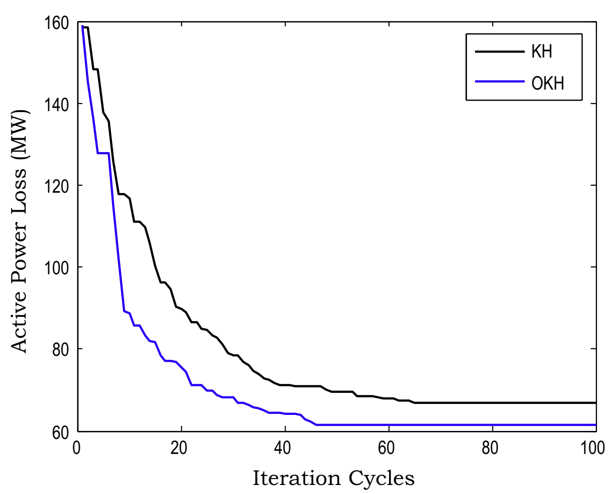

Fig. 10. Loss convergence using KH and OKH of 69-bus system with reconfiguration for composite load for load multiplying factor of 1.0.

Load modelling

As here, four types of loads are considered. The mathematical expression of active and reactive power loads are given as:

$$PL(n) = PL_0(n)(c_1 + c_2|V(n)| + c_3|V(n)|^2) \quad (2)$$

$$QL(n) = QL_0(n)(d_1 + d_2|V(n)| + d_3|V(n)|^2) \quad (3)$$

Here $(c_1,\ d_1)$, $(c_2,\ d_2)$ and $(c_3,\ d_3)$ are the compositions of constant power, constant current and constant impedance loads respectively. Now, for constant power load $c_1 = d_1 = 1$ and $c_2 = d_2 = c_3 = d_3 = 0$; for constant current load $c_2 = d_2 = 1$ and $c_1 = d_1 = c_3 = d_3 = 0$; for constant impedance load $c_3 = d_3 = 1$ and $c_1 = d_1 = c_2 = d_2 = 0$; for composite type load $c_1 = d_1 = 0.4$, $c_2 = d_2 = 0.3$ and $c_3 = d_3 = 0.3$, respectively.

Constraints

The above objective function is subjected to the following constraints:

- Power balance constraint

$$P_m + jQ_n = V_mI_n \quad (4)$$

where I_n is the current at the nth node.

- Voltage limit

The voltage constraint can be taken into account by specifying upper and lower limits of voltage variation at the nodes of the distribution system. This may be expressed as:

$$V_m^{\min} < V_m < V_m^{\max} \quad (5)$$

where $V_m^{\min}$ and $V_m^{\max}$ are the lower and upper limits of bus voltage, respectively.

- Real power limit

$$P^C_{m,\min} \leqslant P^C_m \leqslant P^C_{m,\max} \quad (6)$$

where $P^C_{m,\min}$, $P^C_{m,\max}$ are the lower and upper limits respectively, of active power of the mth capacitor.

- Reactive power limit

$$Q^C_{m,\min} \leqslant Q^C_m \leqslant Q^C_{m,\max} \quad (7)$$

where $Q^C_{m,\min}$, $Q^C_{m,\max}$ are the minimum and maximum allowable reactive powers, respectively, of the mth capacitor.

Table 8
Results of 69-bus system before after reconfiguration for constant power type load for load multiplying factor of 1.5.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	With capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	558.3	459.1	157.6200	156.4675	225.3	172.0222	170.3416
Optimal position of capacitor	NA	61	63	61	61	60	59
Optimal size of capacitor	NA	400	90.0027	99.4827	400	70.0132	96.6112
Opening branches	NA	NA	NA	NA	55–56 64–65 12–13	55–56 62–63 11–12	55–56 62–63 11–12
Closing branches	NA	NA	NA	NA	50–59 27–65 15–46	50–59 27–65 15–46	50–59 27–65 15–46
Min. voltage	0.8566	0.8683	0.9264	0.9256	0.9151	0.9390	0.9387
Voltage stability index	0.5384	0.5685	0.7366	0.7341	0.7013	0.7700	0.7735

Krill herd algorithm

The krill herd (KH) algorithm is a novel meta-heuristic algorithm for solving global optimization problem, proposed by Gandomi et al. [49]. To improve the performance of KH algorithm Wang et al. proposed [50] a series chaotic particle-swarm KH (CPKH) for solving optimization tasks. The herding of the krill individuals is a multi-objective process including two main goals: (i) increasing krill density; (ii) receiving food. In this process, an individual krill moves toward the best solution when it searches for the highest density and food. Krill moves in the multidimensional space, and each krill adjusts its position by:

i. Change in movement due to induction.
ii. Foraging motion.
iii. Random diffusion.

These operators are briefly explained and mathematically expressed as follows:

Change in movement due to induction

The krill individuals try to maintain a high density and move due to their mutual effects. The velocity of each krill is dynamically adjusted by the local, target and repulsive vector. For a krill individual, this movement can be defined as:

Table 9
Results of 69-bus system before after reconfiguration for constant current type load for load multiplying factor of 1.5.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	With capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	429.7	363.0	140.8236	137.5949	195.3	148.1844	146.2555
Optimal position of capacitor	NA	61	61	61	61	58	59
Optimal size of capacitor	NA	400	52.1431	99.4157	400	93.9163	96.4592
Opening branches	NA	NA	NA	NA	57–58	13–14	13–14
					64–65	54–55	54–55
					12–13	61–62	61–62
Closing branches	NA	NA	NA	NA	50–59	50–59	50–59
					27–65	27–65	27–65
					15–46	15–46	15–46
Min. voltage	0.8754	0.8840	0.9290	0.9309	0.9215	0.9465	0.9468
Voltage stability index	0.5872	0.6107	0.7448	0.7509	0.7212	0.7969	0.7980

Table 10
Results of 69-bus system before after reconfiguration for constant impedance type load for load multiplying factor of 1.5.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	With capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	351.9	302.2	125.8171	123.0069	172.9	136.4686	134.7266
Optimal position of capacitor	NA	61	64	61	61	59	59
Optimal size of capacitor	NA	400	91.1090	99.8420	400	81.3034	99.5243
Opening branches	NA	NA	NA	NA	55–56	13–14	13–14
					64–65	54–55	54–55
					12–13	61–62	61–62
Closing branches	NA	NA	NA	NA	50–59	50–59	50–59
					27–65	27–65	27–65
					15–46	15–46	15–46
Min. voltage	0.8881	0.8950	0.9378	0.9352	0.9266	0.9489	0.9502
Voltage stability index	0.6220	0.6417	0.7726	0.7650	0.7373	0.8051	0.8097

Table 11
Results of 69-bus system before after reconfiguration for composite type load for load multiplying factor of 1.5.

Status of reconfiguration	Without reconfiguration				With reconfiguration		
	Without capacitor placement	With capacitor placement			With capacitor placement		
		Fuzzy approach [30]	KH	OKH	Fuzzy approach [30]	KH	OKH
Power loss (kW)	444.0	373.7	141.2781	139.5266	198.5	155.8284	154.5193
Optimal position of capacitor	NA	61	62,68	61	61	59	59
Optimal size of capacitor	NA	400	91.0228	99.8696	400	90.2897	99.9156
Opening branches	NA	NA	NA	NA	55–56	55–56	55–56
					64–65	62–63	62–63
					12–13	11–12	11–12
Closing branches	NA	NA	NA	NA	50–59	50–59	50–59
					27–65	27–65	27–65
					15–46	15–46	15–46
Min. voltage	0.8731	0.8822	0.9297	0.9304	0.9208	0.9420	0.9426
Voltage stability index	0.5812	0.6056	0.7472	0.7491	0.7189	0.7847	0.7869

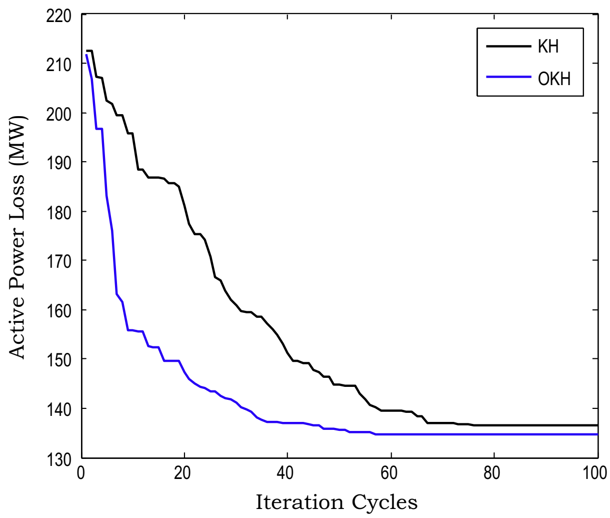

Fig. 11. Loss convergence using KH and OKH of 69-bus system with reconfiguration for constant impedance load for load multiplying factor of 1.5.

$$M_i^{new} = \gamma_i M_i^{\max} + \omega_n M_i^{old} \tag{8}$$

where

$$\gamma_i = \gamma_i^{new} + \gamma_i^{t\arg et} \tag{9}$$

$$\gamma_i^{new} = \sum_{j=1}^{M_S} P_{ij} x_{ij} \tag{10}$$

$$P_{ij} = \frac{P_i - P_j}{P_W - P_B}; \tag{11}$$

$$x_{ij} = \frac{x_i - x_j}{|x_i - x_j| + rand(0,1)}; \tag{12}$$

$$\gamma_i^{t\arg et} = 2\left(rand(0,1) + \frac{i}{i_{\max}}\right) P_i^{best} x_i^{best} \tag{13}$$

where $M_i^{\max}$ is the maximum induced motion; M_i^{old} is the last induced motion; ω_n is the inertia weight of the motion induced; γ_i^{new}, $\gamma_i^{t\arg et}$ are the local and target effects respectively. P_W, P_B are the worst and best position, respectively, of the population; P_i, P_j are objective values of the ith and the jth individual, respectively; i, $i_{\max}$ are the current and maximum iteration number.

To identify the neighbouring members of each krill individual, a sensing distance (S_{di}) parameter is used. If the distance between two individual krill is less than the sensing distance then that particular krill is considered as neighbour of the other krill. It is determine using the following formula:

$$SD = \frac{1}{5S_P} \sum_{j=1}^{S_P} |x_i - x_j| \tag{14}$$

where S_P is the number of neighbouring krill individuals; x_i and x_j are the position of the ith and the jth krill, respectively.

Foraging motion

The first motion M_F covered two parts: the current food location and the information about the previous location. For the ith krill, the foraging motion is mathematically formulated as:

$$M_F = V_f a_i + \omega_f M_F^{old} \tag{15}$$

where

$$a_i = a_i^{food} + a_i^{best} \tag{16}$$

M_F is the first motion; V_f is the foraging speed; ω_f is the inertia weight of the foraging motion in (0,1); M_F^{old} is the last foraging motion.

Physical diffusion

The diffusion process of the krill individuals is considered as a random phenomenon. It may be represented in terms of a maximum diffusion speed and a random directional factor and mathematically expressed as:

$$D_P = D_P^{MAX} \gamma \tag{17}$$

where D_P^{MAX} is the maximum diffusion speed; γ is the oriented vector within −1 and 1.

Position update

According to the three above analyzed action, the time dependent position from time t to $t + \Delta t$ can be formulated by the following equation:

$$x_i(t + \Delta t) = x_i(t) + \Delta t \frac{dx_i}{dt} \tag{18}$$

$$\Delta t = c_T \sum_{j=1}^{n_V} (uB_j - lB_j) \tag{19}$$

$$\frac{dx_i}{dt} = M_i + F_i + D_i \tag{20}$$

where M_i is the motion induced by krill individuals; F_i is the foraging motion; D_i is the physical diffusion; n_V is the total number of variables; uB_j, lB_j are lower and upper bounds of the jth variables; c_T is the position constant.

Application of the genetic operators

In order to improve the performance and convergence speed, the crossover and mutation operation of DE are integrated with krill herd. These two operations are described below:

Crossover

In this stage, each krill individually update its position by position updating equation. The kth components of the ith krill may be updated by:

$$x_{k,j} = \begin{cases} x_{P,j} & \text{if } rand < C_R \\ x_{k,j} & else \end{cases} \quad where \quad P = 1, 2, \ldots, j-1, j+1, \ldots, N \tag{21}$$

where $C_R = 0.2F_k^{best}$.

Mutation

The mutant vectors $X_{k,j}$ perturbing the vector $x_{best,j}$ with the difference of two other randomly selected vectors $x_{r1,j}$ and $x_{r2,j}$ as per following equation.

$$x_{k,j}^{Mu} = x_{best,j} + P_m(x_{r1,j} - x_{r2,j}) \tag{22}$$

The updated position of $x_{k,j}^{MOD}$ is selected from $x_{k,j}^{Mu}$ and $x_{k,j}$ using mutation probability P_m as follows:

$$x_{k,j}^{MOD} = \begin{cases} x_{k,j}^{Mu} \text{ if } rand \leqslant P_m \\ x_{k,j} \text{if } rand > P_m \end{cases} \quad (23)$$

where $P_m = \frac{0.05}{F_k^{best}}$.

Opposition-based learning

Opposition-based learning (OBL) is introduced by Tizhoosh [51], to improve computational efficiency and to accelerate the convergence rate of different optimization techniques. Some of the application of OBL in the soft computing field includes opposition based DE (ODE) [52], opposition based GA (OGA) [53].

There are some definitions used in OBL, as follows:

Opposite number: Let $R \in [A, B]$ be a real number, then the opposite number $\mathring{R}$ is defined as:

$$\mathring{R} = A + B - R \quad (24)$$

Opposite point: Let $P = (R_1, R_2, \ldots R_m)$ be an m-dimensional vector, where $R_i \in [A_i, B_i]$ and $i = 1, 2, \ldots m$. The opposite point $\mathring{P}$ is defined by:

$$\mathring{P} = (\mathring{R}_1, \mathring{R}_2, \ldots, \mathring{R}_m) \text{ where, } \mathring{R}_i = A_i + B_i - R_i \quad (25)$$

Now by employing the opposite point definition, the opposition-based optimization can be defined as follows:

Let $P = (R_1, R_2, \ldots, R_m)$ be a point in m-dimensional space. Assume $f(\bullet)$ is a fitness function which is used to measure the candidate's fitness. According to the definition of the opposite point, $\mathring{P} = (\mathring{R}_1, \mathring{R}_2, \ldots, \mathring{R}_m)$ is the opposite of $P = (R_1, R_2, \ldots, R_m)$. Now, if $f(\mathring{P}) \geqslant f(P)$, then point P can be replaced with $\mathring{P}$, otherwise keep the current point P. Hence, the current point and its opposite point are evaluated simultaneously in order to continue with the fitter one.

Opposition based optimization

Initialization of opposite population $\mathring{R}$ may be described as follows:

```
for  i = S_P  (S_P = population size)
  for  j = S_C  (S_C = control variable)
    R̊_{i,j} = A_j + B_j − R_{i,j}
  end
end
```

OKH algorithm applied to reconfiguration problem along with capacitor

In this article, the authors proposed OKH algorithm by employing OBL concept in original KH algorithm. The main steps of the proposed OKH approach are listed as follows:

Step 1: Read the system data, constraints, the population size (N_P), the maximum number of iterations, the maximum number of capacitor to be installed in the distribution network and the KH parameters.

Step 2: The size of the capacitor is randomly generated and normalized between the maximum and the minimum operating limits.

Using the location and operating kVAr rating of all the installed capacitor, a vector X_k is created which represents initial position of the kth agent for the optimal capacitor placement problem.

$$X_k = [loc_{k,1}, loc_{k,2}, \ldots, loc_{k,l}, \ldots loc_{k,N}, Q_{k,1}, Q_{k,2} \ldots Q_{k,l} \ldots, Q_{K,N}] \quad (26)$$

where $loc_{k,l}$ is the location of the lth capacitor and $Q_{k,l}$ is the size of the lth capacitor

Depending upon the population size, initial solution X is created which is given by:

$$X = [X_1, X_2, \ldots, X_k, \ldots, X_{Np}] \quad (27)$$

Step 3: If voltage difference across the tie switches is maximum, go to next step. Otherwise discard that tie switch.

Step 4: Run the load flow to find the real power losses. In this article a direct load flow algorithm based on the bus-injection to branch-current (BIBC) matrix and the branch-current to bus-voltage (BCBV) matrix [54] are used.

Step 4: Update motion of each krill individual by velocity update equation, foraging motion and random diffusion using (9), (15) and (18).

Step 5: Using (19), position of each krill individuals are modified.

Step 6: Generate opposite population using jumping rate as described as below:

```
If rand < j_r
  for i = 1 : N_p
    for j = 1 : N_m
      N̊_i = A_i + B_i − N_i
    end
  end
end
```

Step 7: Choose N_p fittest individuals from current population and the oppositional population.

Step 8: Check whether the independent variables (rating of capacitor) violate the operating limits or not. If any independent variable is less than the minimum level it is made equal to minimum value and if it is greater than the maximum level, it is made equal to maximum level.

Step 9: Repeat steps 3–8 until the current iteration number reaches the maximum iteration number.

Results and discussion

To verify the effectiveness of the proposed KH and OKH algorithms, they are demonstrated through two examples. The authors used standard 33-bus and 69-bus radial distribution systems for reconfiguration with capacitor placement to determine the optimal location and size of capacitor in order to minimize active power loss. The proposed methods are implemented in MATLAB software and simulations are performed on personal computer having core i3 processor, 2.53 GHz, and 3 GB RAM. The proposed KH and OKH algorithms are run for 50 population size and 100 iterations for each case and the best results are shown in the corresponding Tables.

The KH algorithm input parameters used in [49] are used for this simulation study and these parameters are as follows: the maximum induced motion, $M_i^{\max} = 0.01$; the maximum diffusion speed, $D_P^{MAX} = 0.05$; the position constant, $c_T = 0.2$; the inertia weights, $\omega_n, \omega_f = 0.9$ at the beginning to emphasize exploration capability of the search process and these values are linearly decreased to 0.1 at the end to exploit the search space.

33-bus radial distribution system for multiplying factor 1.0

Initially, to show the effectiveness of proposed OKH and KH methods, they are tested on small 33-bus distribution system consisting of 37 branches. The single line diagram of 33-bus radial distribution system is shown in Fig. 1 and the line data and load data are given in [55] with rated voltage of 12.66 kV. For 33-bus distribution system, five tie-switches are used. Figs. 2–4 depict the reconfiguration diagram obtained by OKH algorithm for three different cases of constant power type, constant current type and constant impedance type. To validate the effectiveness of the proposed methods, optimal reconfiguration is made for three different types of loads. After load flow, a real power loss without capacitor at rated load is 210.998 kW for constant power type load. Table 1 shows the power loss, minimum voltage, optimal location and optimal size of capacitor before and after reconfiguration by KH and OKH techniques. It is pointed out from Table 1 that after reconfiguration without capacitor power loss obtained are 127.6838 kW and 115.0892 kW by KH and OKH algorithms compared to NSGA method [44]. From Tables 2 and 3 it can be easily demonstrated that OKH produces much better result when compared to KH by considering the cases of without reconfiguration and with reconfiguration. It may also be noted from above results that for any types of load after reconfiguring of the system its gives better power losses than those obtained before reconfiguration. The convergence characteristics of power loss using OKH and KH algorithms for constant power load without reconfiguration with load multiplying factor of 1.0 are illustrated in Fig. 5.

69-bus radial distribution system for multiplying factor 1.0

The proposed methods are further implemented on 69-bus radial distribution system consisting of 73 branches (including tie branches). The single line diagram of 69-bus radial distribution system is shown in Fig. 6 and the line data and load data are given in [56] with rated voltage of 12.66 kV. After load flow, a real power loss without capacitor at rated load is 224.2 KW. To validate the effectiveness of the proposed method to find optimal location, size of capacitor, its results are compared with other techniques. After applying the proposed OKH algorithm three different reconfiguration diagrams shown in Figs. 7–9 for four different types of load of constant power type constant impedance type, constant current type and composite type are obtained. It is to be noted that before applying proposed method, the number of tie switches are five but after reconfiguration three tie switches are in operation. Remaining two is discarded because voltages of those buses are not within tolerance limit. From Tables 4–7 it can be shown that losses are decreased with capacitor placement without reconfiguration than without capacitor for different types of loads. But after reconfiguration with capacitor placement they show better results than previous one. It may further be noted from the simulation results reported in Tables 4–7 that the total power loss using OKH are 67.6531 kW, 61.4412 kW, 34.7554 kW and 61.3969 kW which are less than KH and fuzzy multi-objective approach [30]. This shows that the proposed OKH is more effective than the other methods. The minimum bus voltages and voltage stability index obtained by proposed method is less than those obtained before reconfiguration without capacitor placement condition. The convergence characteristics for composite type load with reconfiguration using KH and OKH are shown in Fig. 10. From the convergence characteristics it is observed that OKH converges in less iteration as compared to the KH algorithm.

69-bus radial distribution system for multiplying factor 1.5

To show the performance of the proposed method on stressed condition, they are implemented on the same system when active and reactive loads of all nodes are increased to 150%. The comparative results of different load types are listed in Tables 8–11, it can be seen that for all four cases, the results obtained by proposed OKH is better than KH. Similar reconfigurations are also observed for constant power and composite load (Fig. 7), constant current load and constant impedance load (Fig. 8). The convergence characteristics of active power loss obtained by OKH and KH for constant impedance load are depicted in Fig. 11.

From the distribution loss convergence graph for all the test systems of the proposed OKH algorithm, it may be observed that the objective value converges smoothly to the optimum solution without any abrupt oscillations. This confirms the convergence reliability of the proposed OKH method.

Hence, from the above simulation results and convergence characteristics, it may finally be concluded that for reconfiguration problem of the radial distribution system, the proposed OKH method is proved to be an efficient population based optimization technique.

Conclusion

Krill herd (KH) algorithm, a recently developed population based optimization technique, has been successfully implemented to do optimal reconfiguration of distribution system problems. However, due to slow convergence and local minima, KH fails to give global results in case of nonlinear optimization problems. To enhance the convergence speed, OBL is integrated with original KH algorithm. The OKH achieves superior quality solutions with higher convergence speed and efficiency compared to other methods. Therefore, OKH is considered as one of the strongest tools to solve RDN problems. Analysis also reveals that the real power loss of radial distribution system can be minimized by reconfigured the network. In future, OKH can also be created a new path in the field of power system which may encourage the researcher to apply this freshly developed algorithm to solve different complicated power system optimization problems like automatic generation control, optimal power flow, economic emission load dispatch, hydro-thermal scheduling, power system stability, etc.

References

[1] Grainger JJ, Lee SH. Optimum size and location of shunt capacitors for reduction of losses on distribution feeders. IEEE Trans Power Appar Syst 1981;100(3):1105–18.

[2] Hogan PM, Rettkowski JD, Bala JL. Optimal capacitor placement using branch and bound. In: Proceedings of the 37th annual North American Power, symposium 2005; 23rd–25th October: 84–9.

[3] Khodr HM, Yusta JM, Vale Z, Ramos C. An efficient method for optimal location and sizing of fixed and switched shunt capacitors in large distribution systems. IEEE power and energy society general meeting 2008; 20th–24th July: 1–9.

[4] Khodr HM, Olsina FG, Jesus DOD, Yusta JM. Maximum savings approach for location and sizing of capacitors in distribution systems. Elect Power Syst Res 2008;78(7):1192–203.

[5] Ching TS, Lee CS. Feeder reconfiguration and capacitor setting for loss reduction of distribution systems. Elect Power Syst Res 2001;58(2):97–102.

[6] Singh SP, Rao AR. Optimal allocation of capacitors in distribution systems using particle swarm optimization. Int J Elect Power Energy Syst 2012;43(1):1267–75.

[7] Kalyuzhny A, Levitin G, Elmakis D, Haim HB. System approach to shunt capacitor allocation in radial distribution system. Elect Power Syst Res 2000;56(1):51–60.

[8] Sydulu M, Reddy VVK. Index and GA based optimal location and sizing of distribution system capacitors. In: IEEE power engineering society general meeting 2007; 24th–28th June: 1–4.

[9] Mandal KK, Bhattacharya B, Tudu B, Chakraborty NA. Novel population-based optimization algorithm for optimal distribution capacitor planning. In: International conference on energy, automation, and signal (ICEAS) 2011; 28th–30th December: 1–6.

[10] Sarfi RJ, Salama MMA, Chikhani AY. A survey of the state of the art in distribution system reconfiguration for system loss reduction. Electric Power Syst Res 1994;31(1):61–70.

[11] Grainger JJ, Lee SH. Optimum size and location of shunt capacitors for reduction of losses on distribution feeders. IEEE Trans Power Apparat Syst 1981;100(3):1105–18.

[12] Francisco LI, Jesús RS, Esther RR. Mixed-integer linear programming model for solving reconfiguration problems in large-scale distribution systems. Electric Power Syst Res 2012;88:137–45.

[13] John FF, Marcos JR, Marina L, Rubén Romero. A mixed-integer LP model for the reconfiguration of radial electric distribution systems considering distributed generation. Electric Power Syst Res 2013;97:51–60.
[14] Pfitscher LL, Bernardon DP, Canha LN, Montagner VF, Garcia VJ, Abaide AR. Intelligent system for automatic reconfiguration of distribution network in real time. Electric Power Syst Res 2013;97:84–92.
[15] Armin EM, Mahmood RH. A new probabilistic approach for distribution network reconfiguration: applicability to real networks. Math Comput Model 2013;57:169–79.
[16] Lopez E, Opazo H, Garica L, Bastard P. Online reconfiguration considering variability demand: applications to real networks. IEEE Trans Power Syst 2004;19(1):549–53.
[17] Khodr HM, Martinez-Crespo J, Matos MA, Pereira J. Distribution systems reconfiguration based on OPF using benders decomposition. IEEE Trans Power Del 2010;24(4):2166–76.
[18] Leonardo W, Oliveira D, Sandoval CJ, Edimar JDO, Pereira JLR, Ivo CSJ, et al. Optimal reconfiguration and capacitor allocation in radial distribution systems for energy losses minimization. Int J Electr Power Energy Syst 2010;32(8):840–8.
[19] Song YH, Wang GS, Johns AT, Wang PY. Distribution network reconfiguration for loss reduction using Fuzzy controlled evolutionary programming. IEE Proc Gene Transm Distrib 1997;144(4):345–50.
[20] Venkatesh B, Ranjan R. Fuzzy EP algorithm and dynamic data structure for optimal capacitor allocation in radial distribution systems. Proc IEE Proc Gen, Transm Distrib 2006;153(1):80–8.
[21] Niknam T. An efficient hybrid evolutionary algorithm based on PSO and HBMO algorithms for multi-objective distribution feeder reconfiguration. Energy Convers Manage 2009;50(8):2074–82.
[22] Chiou JP, Chang CF, Su CT. Variable scaling hybrid differential evolution for solving network reconfiguration of distribution systems. IEEE Trans Power Syst 2005;20(2):668–74.
[23] Ching TS, Chu SL. Network reconfiguration of distribution systems using improved mixed-integer hybrid differential evolution. IEEE Trans Power Del 2003;18(3):1022–7.
[24] Ahuja A, Das S, Pahwa A. An AIS-ACO hybrid approach for multi-objective distribution system reconfiguration. IEEE Trans Power Syst 2007;22(3):1101–11.
[25] Sahoo NC, Prasad K. A fuzzy genetic approach for network reconfiguration to enhance voltage stability in radial distribution systems. Energy Convers Manage 2006;47(18–19):3288–306.
[26] Niknam T, Olamaie J, Khorshidi R. A hybrid fuzzy algorithm for multi-objective distribution feeder reconfiguration. World Appl Sci J 2008;4(2):308–15.
[27] Das D. Reconfiguration of distribution system using fuzzy multi-objective approach. Int J Electr Power Energy Syst 2006;28(5):331–8.
[28] Bernardon DP, Garcia VJ, Ferreira ASQ, Canha LN. Electric distribution network reconfiguration based on a fuzzy multi-criteria decision making algorithm. Electr Power Syst Res 2009;79:1400–7.
[29] Arun M, Aravindhababu P. Fuzzy based reconfiguration algorithm for voltage stability enhancement of distribution systems. Exp Syst Appl 2010;37(10):6974–8.
[30] Banerjee S, Chanda CK, Das D. Reconfiguration of distribution networks based on fuzzy multiobjective approach by considering loads of different types. J Inst Eng India Ser B 2013;94(1):29–42.
[31] Wagner TP, Chikhani AY, Hackam R. Feeder configuration for loss reduction: an application of distribution automation. IEEE Trans Power Del 1991;6(4):1922–31.
[32] Abul'Wafa Ahmed R. A new heuristic approach for optimal reconfiguration in distribution systems. Electr Power Syst Res 2011;81(2):282–9.
[33] Chiang HD, Jean JR. Optimal network reconfigurations in distribution systems: Part II. IEEE Trans Power Del 1990;5(3):1568–74.
[34] Chang HC, Kuo CC. Network reconfiguration in distribution systems using simulated annealing. Electr Power Syst Res 1994;29(3):227–38.
[35] Jeon YJ, Kim JC. Network reconfiguration in radial distribution system using simulated annealing and tabu search. In: Proc IEEE power eng soc winter meet; 2000. p. 2329–33.
[36] Mori H, Ogita Y. A parallel tabu search method for reconfiguration of distribution systems. In: Proceedings of the 2000 IEEE power engineering society summer meeting. vol. 1; 2000. p. 73–8.
[37] Li KK, Chung TS, Chen GJ, Tang GQ. A tabu search approach to distribution network reconfiguration for loss reduction. Electric Power Compon Syst 2004;32(6):571–85.
[38] Zhang D, Fu Z, Zhang L. An improved TS algorithm for loss-minimum reconfiguration in large-scale distribution systems. Electr Power Syst Res 2007;77(5–6):685–94.
[39] Mekhamer SF, Abdelaziz AY, Mohammed FM, Badr MAL. A new intelligent optimization technique for distribution systems reconfiguration. In: Proceedings of the twelfth international middle-east power systems conference, MEPCON'2008. Egypt: South Valley University; 2008.
[40] Abdelaziz AY, Mohamed FM, Mekhamer SF, Badr MAL. Distribution system reconfiguration using a modified Tabu Search algorithm. Electr Power Syst Res 2010;80(8):943–53.
[41] Zhu JZ. Optimal reconfiguration of electric distribution network using refined genetic algorithm. Electr Power Syst Res 2002;62:37–42.
[42] Torres J, Guardado JL, Rivas DF, Maximov S, Melgoza E. A genetic algorithm based on the edge window decoder technique to optimize power distribution systems reconfiguration. Int J Electr Power Energy Syst 2013;45(1):28–34.
[43] Anil S, Gupta N, Niazi KR. Minimal loss configuration for largescale radial distribution systems using adaptive genetic algorithms. In: 16th national power systems conference, 15th–17th December; 2010.
[44] Chandramohan S, Naresh A, Kumudini DRP, Venkatesh B. Operating cost minimization of a radial distribution system in a deregulated electricity market through reconfiguration using NSGA method. Int J Electr Power Energy Syst 2010;32(2):126–32.
[45] Chang CF. Reconfiguration and capacitor placement for loss reduction of distribution systems by ant colony search algorithm. IEEE Trans Power Syst 2008;23(4):747–1755.
[46] Kumar KS, Jayabarathi T. Power system reconfiguration and loss minimization for an distribution systems using bacterial foraging optimization algorithm. Int J Electr Power Energy Syst 2012;36(1):13–7.
[47] Li J, Tang Y, Hua C, Guan X. An improved krill herd algorithm: krill herd with linear decreasing step. Appl Math Comput 2014;234:356–67.
[48] Acharya N, Mahat P, Mithulananthan N. An analytical approach for DG allocation in primary distribution network. Int J Elect Power Energy Syst 2006;28(10):669–78.
[49] Gandomi AH, Alavi AH. Krill herd: a new bio-inspired optimization algorithm. Nonlinear Sci Numer Simul 2012;17(12):4831–45.
[50] Gai-Ge W, Amir HG, Amir HA. A chaotic particle-swarm krill herd algorithm for global numerical optimization. Kybernetes 2013;42(6):962–78.
[51] Tizhoosh HR. Opposition-based learning: a new scheme for machine intelligence. In: Proceedings of international conference on computational intelligence for modeling control and automation; 2005. p. 695–701.
[52] Rahnamayan S, Wang GG. Solving large scale optimization problems by opposition-based differential evolution (ODE), Wseas Trans on Computers, Manuscript received May 10, 2008; revised September 18; 2008.
[53] Muhammad AI, Khan NK, Hasan M. A novel function optimization approach using opposition based genetic algorithm with gene excitation. Int J Innovative Comput, Inform Control 2011;7(7B):4263–76.
[54] Teng JH. A direct approach for distribution system load flow solutions. IEEE Trans Power Del 2003;18(3):882–7.
[55] Kashem MA, Ganapathy V, Jasmon GB, Buhari MI. A novel method for loss minimization in distribution networks. In: Int conf electr utility deregu. restruct. power technologies 2000. London: City University; 2000. p. 251–6. 4–7 April.
[56] Das D. Optimal placement of capacitors in radial distribution system using fuzzy-GA method. Int J Elect Power Energy Syst 2008;30(6–7):361–7.