Distribution power system reconfiguration using whale optimization algorithm

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Article Info

Article history:

Received Oct 7, 2019
Revised Oct 22, 2019
Accepted Mar 3, 2020

Keywords:

Network distribution
Power loss
Reconfiguration
Whale optimization

ABSTRACT

This study discusses how to enhance the power distribution system and one of the most important ways to do that is by reconfiguration of the power system. Reconfiguration means changing the topology of the radial distribution network by changing the status of switches. The objective is to minimize the total power loss and enhance the voltage profile. Many optimization techniques were used to solve this problem such as classical optimization which is proven to be time consuming method and heuristic methods which are more efficient in our problem here. In this paper, the whale optimization algorithm (WOA) which is one of the modern heuristic optimization techniques and it has high efficiency to solve discrete optimization problems, is used to get the optimum case in reconfiguration problem. WOA is applied to (33 bus system, 69 bus system, and 118 bus system) and results are compared to other heuristic methods.

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1. INTRODUCTION

Electric utilities are interested in reducing power loss to be more competitive. The voltage drop problem can occur when using radial systems with long distances feeder and large loads. To overcome such a problem, different methods can be applied such as: installing distributed generators (DGs) [1, 2], capacitor placement [3] and network reconfiguration which is introduced in this paper. Network reconfigurations mean changing the topology of the network by varying the status of switches (open/closed). There are two types of switches in the distribution power systems:

- Sectionalized switches (normally closed)
- Tie switches (normally open)

These switches in power systems are used for:

- Protection in case of faults
- Reconfiguration of the power system.

The distribution network reconfiguration is considered as a mixed integer non-linear optimization problem. There are many types of optimization techniques:

- Classical optimization: Depends on some mathematical methods to solve optimization problems such as linear programming, Lagrange method. For large scale problem such as the problem here (reconfiguration), the classical methods consume much time and may be trapped to local optimum solution not the global.

- Heuristic optimization: This type depends on the behavior of something in the nature such as ant colony, gray wolf method, whale optimization method…etc. The main advantage in heuristic methods is less time consuming to solve large scale problems unlike classical methods. The disadvantage in it is that it gives less accurate results.
- Artificial intelligence: Depends on programming and machine learning such as particle swarm.

The network reconfiguration for power loss reduction was firstly introduced by Merlin and Back in 1975 [1]. They used heuristic approach called a branch and-bound-type optimization technique. This technique has a main disadvantage that it is a very time consuming as it has to try 2n configuration where n is the number of branches in the power system. The whale optimization algorithm (WOA) [4] presented in this study mimics the behavior of whales in exploring and hunting the prey. The main difference between this method and other heuristic methods is in the hunting mechanism to catch the prey using either spiral net mechanism or circular net mechanism. WOA has proved its efficiency in solving 29 mathematical optimization problems and 6 structural optimization problems [4]. At section 2 in this article, reconfiguration problem will be formulated in mathematical form. The whale optimization algorithm will be expressed in a mathematical form at section 3, section 4 is dedicated for the implementation of the proposed algorithm to minimize power loss of 33, 69, and 118 bus systems. Then the obtained results are compared to previously applied heuristic methods to prove its efficiency at section 5.

In the last few years, many researchers tried to solve the reconfiguration problem using different methods trying to reach less time-consuming methods and looking for the global optimum. Authors of [5] use grey wolf optimization algorithm which is inspired from hunting strategy of grey wolves to solve reconfiguration problem for (33 bus system, 69 bus system, and 118 bus system). Authors of [6] use fireworks algorithm for solving reconfiguration problem on 33 and 119 bus system. The fireworks algorithm depends on the sparks generated in the explosion. This algorithm selects some quality points at each generation and the search process continues until a spark reaches the optimum. The authors also mentioned that the main disadvantage of the previous methods is represented in the computational time and work done under normal conditions.

Authors of [7] use a binary group search algorithm to solve the reconfiguration problem on IEEE 33 and 69 bus systems. This algorithm depends on animal searching behavior and scanning methodology to get the optimum searching strategy. Authors of [8] use gravitational search algorithm (GSA) to apply on reconfiguration problem 33 and 69 bus system. This algorithm depends on the law of gravity and mass interaction due to Newton’s law. Authors of [9] use ant colony optimization and musician’s behavior inspired to apply on 33 and 118 bus system reconfiguration problems. The ant colony optimization method depends on the behavior of ant to find the shortest path between food and nest via pheromone as indirect communication. The harmonic search optimization depends on the harmony between musicians to come up with a nice harmony. Authors of [10] use a modified particle swarm as a metaheuristic optimization algorithm to solve the reconfiguration problem on 32 nodes and 69 nodes system. This algorithm developed by Kennedy and Eberhart in 1995 and it is inspired by the social behavior of bird flocks and fish schools.

Authors of [11] use bacteria foraging behavior optimization algorithm to solve the reconfiguration problem. This optimization technique is inspired from social foraging behavior of *Escherichia coli* and it has high ability to solve real optimization applications. This method was applied to 33 bus system. Authors of [12] use bee colony optimization algorithm which is inspired from intelligent foraging behavior of honeybee swarm to solve reconfiguration problem on 33 and 119 bus system. Authors of [13] use cuckoo search optimization algorithm which is inspired from brood parasitism of cuckoo species to lay their eggs in the nests of the other species of birds for optimization problems. This algorithm is applied on three different power systems and it proves its efficiency. In this paper, a new heuristic optimization technique is used which is called whale optimization algorithm (WOA). This algorithm is inspired from the whale hunting behavior. It is was proven its efficiency in solving many mathematical optimization models and its high ability to avoid local optimal and its fast convergence. In this article, at section 2 the reconfiguration problem is being formulated in mathematical model. At section 3, the WOA is being illustrated in detail in a mathematical form. At section 4, the algorithm of applying the WOA on the reconfiguration problem is being stated. At section 5, the results are discussed and compared to other heuristic methods.

2. PROBLEM FORMULATION FOR NETWORK RECONFIGURATION

Objective function: minimize power loss $P_{loss} = \sum I^2 R$ for all connections between buses.

Constraints:

Voltage constraint : $V_{\min} < V_i < V_{\max}, \quad i = 1, 2, ...,$ number of buses

Load constraint : $I_{\min} < I_i < I_{\max}, \quad i = 1, 2, ...,$ number of branches

Topology constraint : the system must be radial after reconfiguration

Note:

P_{loss} : total power loss in the system

I_i : the magnitude of the current flowing through branch i

V_i : voltage of bus i

The objective function is calculated from the solution of power flow equations such as the Newton Raphson method. To check system radiality, incidence matrix A is formed with dimensions equal. Number of branches (*M*) * number of buses (*N*) and the elements of this matrix can be formed as follows:

$$A_{ij} = \begin{cases} 0 & \text{in case of the branch } i \text{ not connected to bus } j \\ -1 & \text{in case of the branch } i \text{ from bus } j \\ 1 & \text{in case of the branch } i \text{ is to bus } j \end{cases}$$

Then the column referring to the reference node (usually first column) must be omitted. If determinant (*A*) equals 1 or -1 then the system is radial. If det (*A*) equals zero, then the system is not radial, and some loads may be disconnected.

3. WHALE OPTIMIZATION ALGORITHM

It is a heuristic method discovered in 2016 and it mimics humpback whale hunting strategy. It has many advantages such as local optimum avoidance and fast convergence. Search agents are initialized firstly to search for the optimum (prey) (exploration phase) and then update their positions toward the best search agent near the optimum. We can mathematically express that by (1).

3.1. Exploration phase

$$\begin{aligned} \vec{D} &= |\vec{C}\vec{x}^*(t) - \vec{x}(t)| \\ \vec{x}(t+1) &= \vec{x}^*(t) - \vec{A}.\vec{D} \\ \vec{A} &= 2\vec{a}.\vec{r} - \vec{a} \\ \vec{C} &= 2\vec{r} \end{aligned} \quad (1)$$

Where t is the current iteration, $\vec{A}, \vec{C}$ are the coefficient vectors, $\vec{x}^*(t)$ is the position of best search agent, $\vec{x}(t)$ is the position vector, $\vec{a}$ is linear decrease from 2 to 0 and $\vec{r}$ is random vector in [0, 1].

3.2. Exploitation phase

In exploitation phase, whales use a bubble net attacking method to catch the prey. There are 2 mechanisms for bubble net as shown in Figure 1.

- Shrinking encircling mechanism

$$\vec{x}(t+1) = \vec{x}^*(t) - \vec{A}.\vec{D} \quad (2)$$

- Spiral updating position

$$\vec{x}(t+1) = \overrightarrow{D'}e^{bl}\cos(2\pi l) + \vec{x}^*(t) \quad (3)$$

where $D' = |\vec{x}^*(t) - \vec{x}(t)|$ is the distance between search agent and the prey.

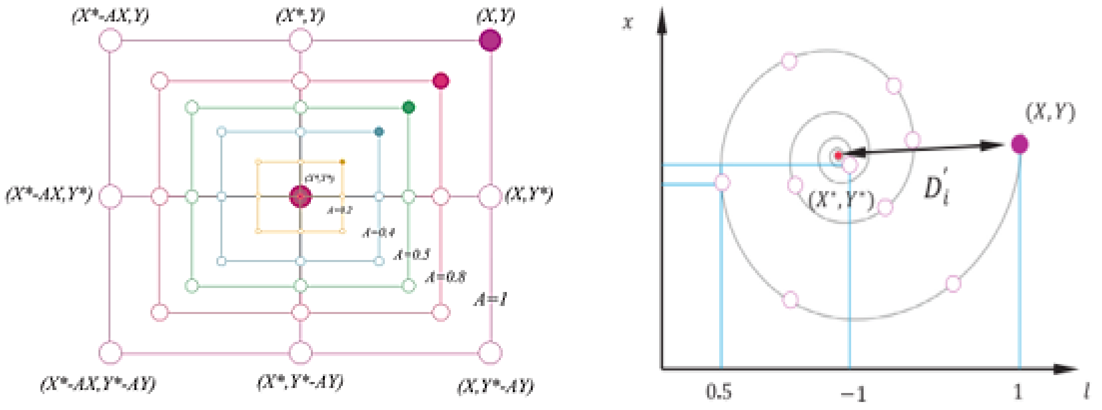
b: constant (usually 1)

l: random number in [0,1]

Usually, humpback uses each mechanism with probability 50% so we can summarize the exploitation phase in the following equations:

$$\vec{x}(t+1) = \begin{cases} \vec{x}^*(t) - \vec{A}.\vec{D} & \text{if } p < 0.5; \\ \overrightarrow{D'}e^{bl}\cos(2\pi l) + \vec{x}^*(t) & \text{if } p \geq 0.5, \end{cases}$$

where p is random number in [0, 1]



(a) (b)

Figure 1. Bubble-net search mechanism implemented in WOA (X∗ is the best solution obtained so far), (a) shrinking encircling mechanism, (b) spiral updating position

The WOA algorithm can be summarized in the following pseudo code:

```
Initialize the whales population Xi (i = 1, 2, ..., n)
Calculate the fitness of each search agent
X*=the best search agent
while (t < maximum number of iterations)
for each search agent
Update a, A, C, l, and p
if1 (p<0.5)
if2 (|A| < 1)
Update the position of the current search agent by the Eq. (1)
else if2 (|A|
Select a random search agent (X_rand )
Update the position of the current search agent by the Eq. (2)
end if2
else if1 (p> 0.5)
Update the position of the current search by the Eq. (3)
end if1
end for
Check if any search agent goes beyond the search space and amend it
Calculate the fitness of each search agent
Update X* if there is a better solution
t=t+1
end while
return X*
```

4. FORMULATION OF WOA FOR SOLVING MINIMUM POWER LOSS RECONFIGURATION PROBLEM

The distribution systems can be described as a matrix with dimensions MxL. Where M is number of branches and L is number of buses. It can be assumed that whales move between branches and select which one is to be open.

Step (1): Initializing the position of search agents

Initial random positions for each search agent are set and selecting random switches to be opened (tie switches). Then the initial configuration is checked whether it is a radial system or not. If the system is radial, we can run a power flow analysis on it to calculate total power loss in the system and minimum bus voltage. Now, we can assume that the best configuration is the initial configuration and then start the next step to change the reconfiguration of the system.

Step (2): Updating positions of search agents

In each iteration (i), a new configuration is produced using (WOA) by selecting some switches to be open. The configuration must be evaluated by 3 important actions:

1. Check system radiality: by forming incidence matrix (A), the system is checked if it is radial or not if the system is not radial, the configuration is discarded and the fitness function (power loss) is set to equal infinity.

2. Run power flow analysis: “Newton Raphson method” is the method used for load flow of the system and check the bus voltage limit. $V_{min} > 0.91$ and $V_{max} < 1$. If the system does not satisfy voltage limit condition, the configuration is discarded also, and the fitness function is set to equal infinity.
3. Evaluate fitness function (P_{loss})

Step (3): Determination of best configuration to get minimum power loss

The process continues until reaching the maximum number of iterations. At each iteration, if fitness function<initial fitness function, then the current configuration is set to be the best configuration

5. RESULTS AND COMPARING WITH OTHER HEURISTIC METHODS

Applying the WOA on 33, 69, and 118 bus systems respectively for minimum power loss reconfiguration problem using MATLAB V2019 executed on processor core i5-7200u @2.5GHz with 8 GB RAM. The number of search agents used in the reconfiguration optimization problems at this study is between (30-50) search agents and the maximum number of iterations equals 500. Newton Raphson power flow algorithm is used in power flow analysis during reconfiguration process to get power loss and minimum voltage of the system. The time consumed to simulate the 33-bus system and get the optimum solution is 3.3 seconds, for 69 bus system 8.8 seconds, and for 118 bus system is 18.34 seconds.

5.1. For 33 bus system

The specifications of the system are shown in Table 1 and initial configuration of 33 bus system is shown in Figure 2. From simulation, as shown in Figure 3 and Table 2 that power loss decreased by 31.1% and voltage profile improved to 0.9372. The results of applying WOA on 33 bus system are compared to other heuristic techniques on the same system in Table 3 and the results were very competitive.

Table 1. Specifications of 33 bus system [14-17]

S_base (MVA)	V_base (kV)	Z_base (ohms)	Resistance and Reactance (ohms)		Resistance and Reactance (pu)*		Conductance and Susceptance (pu)*		Maximum Line Capacity		Bus Number	Nominal Load	
100	12.66	1.602756											
	From	To	R (ohms)	X (ohms)	R (pu)	X (pu)	G (pu)	B (pu)	P (KW)	Q (KVAR)		P (KW)	Q (KVAR)
	1	2	0.0922	0.0470	0.0575	0.0293	13.7980	-7.0337	4600	4600	1	0	0
	2	3	0.4930	0.2511	0.3076	0.1567	2.5814	-1.3148	4100	4100	2	100	60
	3	4	0.3660	0.1864	0.2284	0.1163	3.4772	-1.7709	2900	2900	3	90	40
	4	5	0.3811	0.1941	0.2378	0.1211	3.3394	-1.7008	2900	2900	4	120	80
	5	6	0.8190	0.7070	0.5110	0.4411	1.1213	-0.9680	2900	2900	5	60	30
	6	7	0.1872	0.6188	0.1168	0.3861	0.7179	-2.3729	1500	1500	6	60	20
	7	8	0.7114	0.2351	0.4439	0.1467	2.0311	-0.6712	1050	1050	7	200	100
	8	9	1.0300	0.7400	0.6426	0.4617	1.0263	-0.7374	1050	1050	8	200	100
	9	10	1.0440	0.7400	0.6514	0.4617	1.0218	-0.7243	1050	1050	9	60	20
	10	11	0.1966	0.0650	0.1227	0.0406	7.3490	-2.4297	1050	1050	10	60	20
	11	12	0.3744	0.1298	0.2336	0.0810	3.8215	-1.3249	1050	1050	11	45	30
	12	13	1.4680	1.1550	0.9159	0.7206	0.6744	-0.5306	500	500	12	60	35
	13	14	0.5416	0.7129	0.3379	0.4448	1.0830	-1.4255	450	450	13	60	35
	14	15	0.5910	0.5260	0.3687	0.3282	1.5132	-1.3468	300	300	14	120	80
	15	16	0.7463	0.5450	0.4656	0.3400	1.4006	-1.0228	250	250	15	60	10
	16	17	1.2890	1.7210	0.8042	1.0738	0.4469	-0.5966	250	250	16	60	20
	17	18	0.7320	0.5740	0.4567	0.3581	1.3559	-1.0632	100	100	17	60	20
	2	19	0.1640	0.1565	0.1023	0.0976	5.1150	-4.8811	500	500	18	90	40
	19	20	1.5042	1.3554	0.9385	0.8457	0.5881	-0.5299	500	500	19	90	40
	20	21	0.4095	0.4784	0.2555	0.2985	1.6551	-1.9335	210	210	20	90	40
	21	22	0.7089	0.9373	0.4423	0.5848	0.8227	-1.0878	110	110	21	90	40
	3	23	0.4512	0.3083	0.2815	0.1924	2.4216	-1.6547	1050	1050	22	90	40
	23	24	0.8980	0.7091	0.5603	0.4424	1.0993	-0.8681	1050	1050	23	90	50
	24	25	0.8960	0.7011	0.5590	0.4374	1.1095	-0.8681	500	500	24	420	200
	6	26	0.2030	0.1034	0.1267	0.0645	6.2689	-3.1931	1500	1500	25	420	200
	26	27	0.2842	0.1447	0.1773	0.0903	4.4786	-2.2802	1500	1500	26	60	25
	27	28	1.0590	0.9337	0.6607	0.5826	0.8515	-0.7508	1500	1500	27	60	25
	28	29	0.8042	0.7006	0.5018	0.4371	1.1331	-0.9871	1500	1500	28	60	20
	29	30	0.5075	0.2585	0.3166	0.1613	2.5076	-1.2772	1500	1500	29	120	70
	30	31	0.9744	0.9630	0.6080	0.6008	0.8321	-0.8224	500	500	30	200	600
	31	32	0.3105	0.3619	0.1937	0.2258	2.1886	-2.5509	500	500	31	150	70
	32	33	0.3410	0.5302	0.2128	0.3308	1.3753	-2.1384	100	100	32	210	100
	8**	21**	2.0000	2.0000	1.2479	1.2479	0.4007	-0.4007	-		33	60	40
	9*	15**	2.0000	2.0000	1.2479	1.2479	0.4007	-0.4007	-				
	12*	22**	2.0000	2.0000	1.2479	1.2479	0.4007	-0.4007	-				
	18**	33**	0.5000	0.5000	0.3120	0.3120	1.6028	-1.6028	-				
	25**	29**	0.5000	0.5000	0.3120	0.3120	1.6028	-1.6028	-				

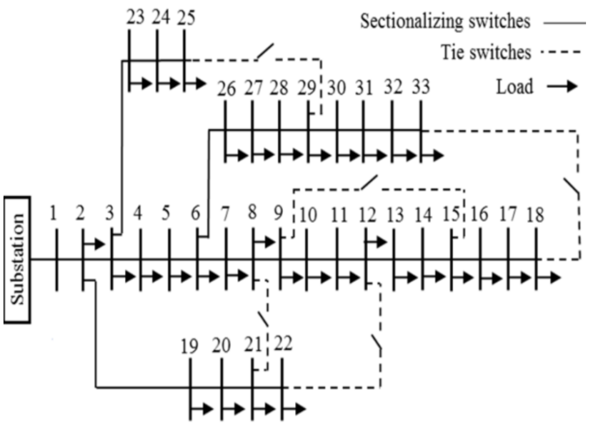


Figure 2. 33-bus single-line diagram

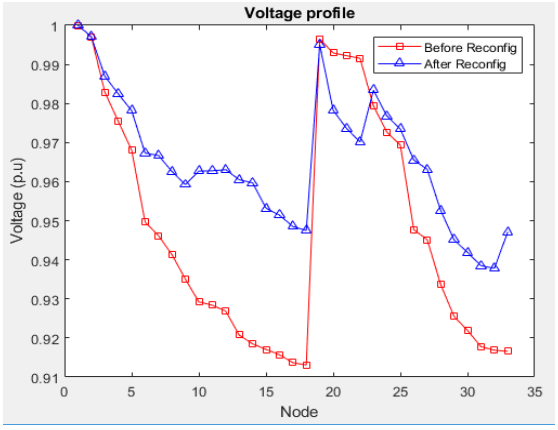


Figure 3. Voltage profile of each bus (33 bus system)

Table 2. Simulation results on 33 bus system using WOA

Simulation results of 33 bus distribution network		
	Before reconfiguration	After reconfiguration
Tie switches:	33, 34, 35, 36, 37	7, 9, 14, 32, 37
Power loss:	202.7052 kW	139.5697 kW
Power loss reduction:	-	31.1465%
Minimum voltage:	0.91308 pu	0.93781 pu

Table 3. Comparing results with other heuristic methods

Heuristic method used in reconfiguration	Before reconfiguration	After reconfiguration
Grey wolf algorithm [5]	Tie switches: 33, 34, 35, 36, 37 P_{loss} = 202.67 kW $V_{\min}$ = 0.9131	Tie switches: 7, 14, 9, 32, 28 P_{loss} = 139.51 kW $V_{\min}$ = 0.9378
Fireworks algorithm [6]	Tie switches: 33, 34, 35, 36, 37 P_{loss} = 202.67 kW $V_{\min}$ = 0.9131	Tie switches: 7, 14, 9, 32, 28 P_{loss} = 139.98 kW $V_{\min}$ = 0.9413
Binary group search [7]	Tie switches: 33, 34, 35, 36, 37 P_{loss} = 202.67 kW $V_{\min}$ = 0.9131	Tie switches: 6-7, 13-14, 8-9, 31-32, 24-28 P_{loss} = 139.5 kW $V_{\min}$ = 0.9378
Gravitational search algorithm [8]	Tie switches: 33, 34, 35, 36, 37 P_{loss} = 202.4 kW $V_{\min}$ = 0.9237	Tie switches: 7, 14, 28, 9, 32 P_{loss} = 134.61 kW $V_{\min}$ = 0.9604
Ant colony optimization [9]	Tie switches: 33, 34, 35, 36, 37 P_{loss} = 203 kW $V_{\min}$ = 0.9131	Tie switches: 6-7, 13-14, 8-9, 31-32, 24-28 P_{loss} = 139.5 kW $V_{\min}$ = 0.9378
Modified particle swarm [10]	Tie switches: 33, 34, 35, 36, 37 P_{loss} = 202.67 kW $V_{\min}$ = 0.9131	Tie switches: 7-8, 14-15, 9-10, 28-29 P_{loss} = 139.5 kW $V_{\min}$ = 0.9378
Bacteria foraging optimization algorithm [11]	P_{loss} = 202.7053 kW	P_{loss} = 135.78 kW Tie switches: 7, 9, 13, 14, 32
Bee colony optimization [12]	P_{loss} = 202.7053 kW $V_{\min}$ = 0.91308	P_{loss} = 139.5 kW $V_{\min}$ = 0.9437
WOA (proposed method)	Tie switches: 33, 34, 35, 36, 37 P_{loss} = 202.7053 kW $V_{\min}$ = 0.91308	Tie switches: 7-8, 9-10, 14-15, 32-33, 25-29 P_{loss} = 139.5697 kW $V_{\min}$ = 0.93781

5.2. For 69 bus system

The initial configuration of 69 bus system is shown in Figure 4 and the specifications of the system are shown in Table 4. It is shown from simulation results in Figure 5 and Table 5 that power loss reduced by 55.57% and voltage profile improved to 0.9427. It is shown from simulation results that applying WOA on 69 bus reconfiguration problem helps in reducing power loss by 55.58% and improving voltage profile to 0.942 instead of 0.909. The results of applying WOA on 69 bus system are compared to other heuristic techniques on the same system in Table 6 and the results were very competitive.

Table 4. The specifications of 69 bus system [16, 17]

S base MVA	V_base (kV)	Z_base (ohms)	Resistance and Reactance (ohms)		Resistance and Reactance (pu)*		Conductance and Susceptance (pu)*		Maximum Line Capacity	Bus Number	Nominal Load	
100	12.66	1.602756										
Branch Number	From	To	Resistance (ohms)	Reactance (ohms)	R (pu)	X (pu)	G (pu)	B (pu)	S (KVA)		P (KW)	Q (KVAR)
	1	2	0.0005	0.0012	0.0003	0.0007	474.1882	-1138.0516	10761	1	0	0
	2	3	0.0005	0.0012	0.0003	0.0007	474.1882	-1138.0516	10761	2	0	0
	3	4	0.0015	0.0036	0.0009	0.0022	158.0627	-379.3505	10761	3	0	0
	4	5	0.0251	0.0294	0.0157	0.0183	26.9205	-31.5324	5823	4	0	0
	5	6	0.3660	0.1864	0.2284	0.1163	3.4772	-1.7709	1899	5	0	0
	6	7	0.3811	0.1941	0.2378	0.1211	3.3394	-1.7008	1899	6	2.6	2.2
	7	8	0.0922	0.0470	0.0575	0.0293	13.7980	-7.0337	1899	7	40.4	30
	8	9	0.0493	0.0251	0.0308	0.0157	25.8180	-13.1446	1899	8	75	54
	9	10	0.8190	0.2707	0.5110	0.1689	1.7642	-0.5831	1455	9	30	22
	10	11	0.1872	0.0619	0.1168	0.0386	7.7179	-2.5520	1455	10	28	19
	11	12	0.7114	0.2351	0.4439	0.1467	2.0311	-0.6712	1455	11	145	104
	12	13	1.0300	0.3400	0.6426	0.2121	1.4032	-0.4632	1455	12	145	104
	13	14	1.0440	0.3450	0.6514	0.2153	1.3841	-0.4574	1455	13	8	5
	14	15	1.0580	0.3496	0.6601	0.2181	1.3658	-0.4513	1455	14	8	5.5
	15	16	0.1966	0.0650	0.1227	0.0406	7.3490	-2.4297	1455	15	0	0
	16	17	0.3744	0.1238	0.2336	0.0772	3.8589	-1.2760	1455	16	45.5	30
	17	18	0.0047	0.0016	0.0029	0.0010	305.5965	-104.0328	2200	17	60	35
	18	19	0.3276	0.1083	0.2044	0.0676	4.4104	-1.4580	1455	18	60	35
	19	20	0.2106	0.0690	0.1314	0.0431	6.8727	-2.2517	1455	19	0	0
	20	21	0.3416	0.1129	0.2131	0.0704	4.2299	-1.3980	1455	20	1	0.6
	21	22	0.0140	0.0046	0.0087	0.0029	103.3274	-33.9504	1455	21	114	81
	22	23	0.1591	0.0526	0.0993	0.0328	9.0813	-3.0024	1455	22	5	3.5
	23	24	0.3463	0.1145	0.2161	0.0714	4.1721	-1.3795	1455	23	0	0
	24	25	0.7488	0.2475	0.4672	0.1544	1.9296	-0.6378	1455	24	28	20
	25	26	0.3089	0.1021	0.1927	0.0637	4.6776	-1.5461	1455	25	0	0
	26	27	0.1732	0.0572	0.1081	0.0357	8.3438	-2.7556	1455	26	14	10
	3	28	0.0044	0.0108	0.0027	0.0067	51.8539	-127.2777	10761	27	14	10
	28	29	0.0640	0.1565	0.0399	0.0976	3.5881	-8.7739	10761	28	26	18.6
	29	30	0.3978	0.1315	0.2482	0.0820	3.6321	-1.2007	1455	29	26	18.6
	30	31	0.0702	0.0232	0.0438	0.0145	20.5832	-6.8024	1455	30	0	0
	31	32	0.3510	0.1160	0.2190	0.0724	4.1166	-1.3605	1455	31	0	0
	32	33	0.8390	0.2816	0.5235	0.1757	1.7169	-0.5763	2200	32	0	0
	33	34	1.7080	0.5646	1.0657	0.3523	0.8459	-0.2796	1455	33	14	10
	34	35	1.4740	0.4873	0.9197	0.3040	0.9802	-0.3241	1455	34	9.5	14
	3	36	0.0044	0.0108	0.0027	0.0067	51.8539	-127.2777	10761	35	6	4
	36	37	0.0640	0.1565	0.0399	0.0976	3.5881	-8.7739	10761	36	26	18.55
	37	38	0.1053	0.1230	0.0657	0.0767	6.4374	-7.5195	5823	37	26	18.55
	38	39	0.0304	0.0355	0.0190	0.0221	22.3052	-26.0472	5823	38	0	0
	39	40	0.0018	0.0021	0.0011	0.0013	377.1191	-439.9722	5823	39	24	17
	40	41	0.7283	0.8509	0.4544	0.5309	0.9305	-1.0872	5823	40	24	17
	41	42	0.3100	0.3623	0.1934	0.2260	2.1853	-2.5540	5823	41	1.2	1
	42	43	0.0410	0.0478	0.0256	0.0298	16.5698	-19.3179	5823	42	0	0
	43	44	0.0092	0.0116	0.0057	0.0072	67.2690	-84.8174	5823	43	6	4.3
	44	45	0.1089	0.1373	0.0679	0.0857	5.6834	-7.1656	5823	44	0	0
	45	46	0.0009	0.0012	0.0006	0.0007	641.1024	-854.8032	6709	45	39.22	26.3
	4	47	0.0034	0.0084	0.0021	0.0052	66.3586	-163.9448	10761	46	39.22	26.3
	47	48	0.0851	0.2083	0.0531	0.1300	2.6939	-6.5939	10761	47	0	0
	48	49	0.2898	0.7091	0.1808	0.4424	0.7915	-1.9368	10761	48	79	56.4
	49	50	0.0822	0.2011	0.0513	0.1255	2.7914	-6.8290	10761	49	384.7	274.5
	8	51	0.0928	0.0473	0.0579	0.0295	13.7095	-6.9877	1899	50	384.7	274.5
	51	52	0.3319	0.1114	0.2071	0.0695	4.3401	-1.4567	2200	51	40.5	28.3
	52	53	0.1740	0.0886	0.1086	0.0553	7.3147	-3.7246	1899	52	3.6	2.7
	53	54	0.2030	0.1034	0.1267	0.0645	6.2689	-3.1931	1899	53	4.35	3.5
	54	55	0.2842	0.1447	0.1773	0.0903	4.4786	-2.2802	1899	54	26.4	19
	55	56	0.2813	0.1433	0.1755	0.0894	4.5237	-2.3045	1899	55	24	17.2
	56	57	1.5900	0.5337	0.9920	0.3330	0.9060	-0.3041	2200	56	0	0
	57	58	0.7837	0.2630	0.4890	0.1641	1.8381	-0.6168	2200	57	0	0
	58	59	0.3042	0.1006	0.1898	0.0628	4.7493	-1.5706	1455	58	0	0
	59	60	0.3861	0.1172	0.2409	0.0731	3.8009	-1.1538	1455	59	100	72
	60	61	0.5075	0.2585	0.3166	0.1613	2.5076	-1.2772	1899	60	0	0
	61	62	0.0974	0.0496	0.0608	0.0309	13.0668	-6.6542	1899	61	1244	888
	62	63	0.1450	0.0738	0.0905	0.0460	8.7793	-4.4683	1899	62	32	23
	63	64	0.7105	0.3619	0.4433	0.2258	1.7911	-0.9123	1899	63	0	0
	64	65	1.0410	0.5302	0.6495	0.3308	1.2225	-0.6226	1899	64	227	162
	11	66	0.2012	0.0611	0.1255	0.0381	7.2934	-2.2148	1455	65	59	42
	66	67	0.0047	0.0014	0.0029	0.0009	313.2205	-93.2997	1455	66	18	13
	12	68	0.7394	0.2444	0.4613	0.1525	1.9541	-0.6459	1455	67	18	13
	68	69	0.0047	0.0016	0.0029	0.0010	305.5965	-104.0328	1455	68	28	20
	11**	43**	0.5000	0.5000	0.3120	0.3120	1.6028	-1.6028	566	69	28	20
	13**	21**	0.5000	0.5000	0.3120	0.3120	1.6028	-1.6028	566			
	15**	46**	1.0000	1.0000	0.6239	0.6239	0.8014	-0.8014	400			
	50**	59**	2.0000	2.0000	1.2479	1.2479	0.4007	-0.4007	283			
	27**	65**	1.0000	1.0000	0.6239	0.6239	0.8014	-0.8014	400			

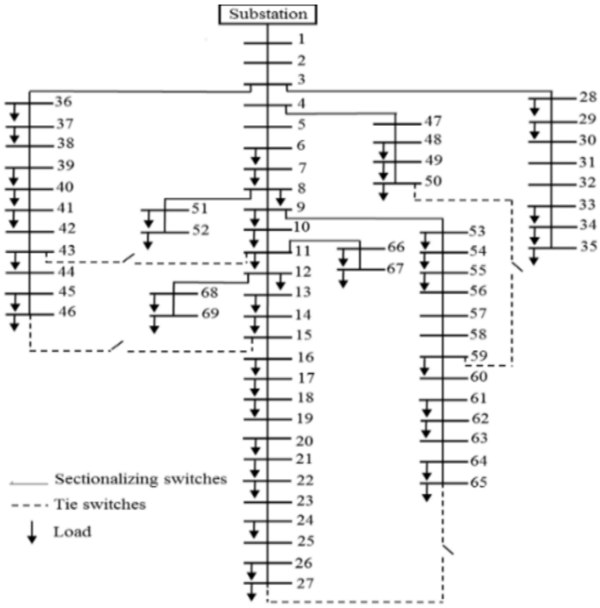


Figure 4. 69-bus single-line diagram

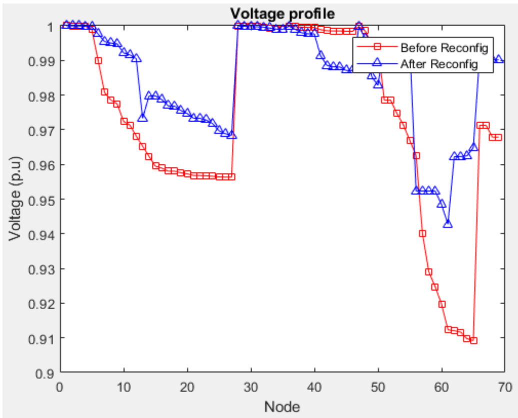


Figure 5. Voltage profile of each bus (69 bus system)

Table 5. Simulation results for applying WOA on 69 bus system

Simulation results of 69 bus distribution network		
	Before reconfiguration	After reconfiguration
Tie switches :	69 70 71 72 73	12 13 55 61 69
Power loss :	225.0007 kW	99.949 kW
Power loss reduction:	-	55.5784 %
Minimum voltage :	0.90919 pu	0.94275 pu

Table 6. Comparing results with other heuristic methods

Heuristic method used in 69 bus case	Before reconfiguration	After reconfiguration
Grey wolf optimizer [5]	P_{loss} = 224.78 kW $V_{\min}$ = 0.909	P_{loss} = 99.58 kW $V_{\min}$ = 0.942
Binary group search [7]	Tie switches: 11-43, 13-21, 15-46, 50-59, 27-65 P_{loss} = 224.99 kW $V_{\min}$ = 0.909	P_{loss} = 98.78 kW $V_{\min}$ = 0.9495
Gravitational search algorithm [8]	P_{loss} = 225.007 kW $V_{\min}$ = 0.909	P_{loss} = 98.5718 kW
Modified particle swarm [10]	P_{loss} = 20.89 kW	P_{loss} = 9.4 kW
WOA (proposed method)	P_{loss} = 225.007 kW $V_{\min}$ = 0.909	Tie switches: 12, 13, 55, 61, 69 P_{loss} = 99.949 kW $V_{\min}$ = 0.942

5.3. For 118 bus system

The initial configuration of 118 bus system is shown in Figure 6. The specification of the 118 bus distribution system is mentioned in [18]. It is shown from Table 7 and Figure 7 that reconfiguration of 118 bus system contributes to decrease power loss of the system by 32.999% and enhance the minimum voltage profile of the system from 0.8686 per unit to 0.932 per unit. The results of applying WOA on 118 bus system are compared to other heuristic techniques on the same system in Table 8 and the results were very competitive.

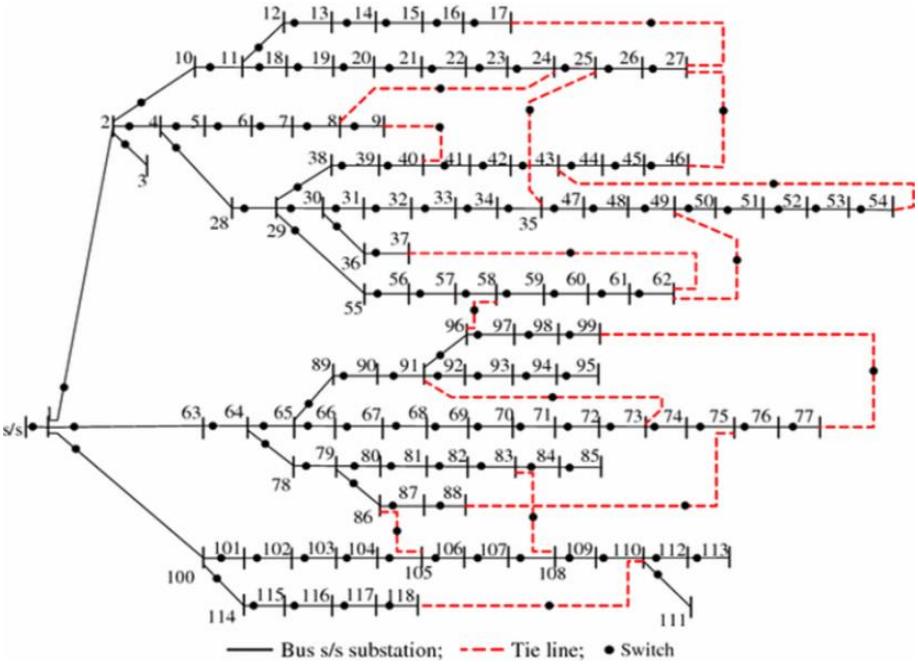


Figure 6. 118 bus distribution system

Table 7. Simulation results after reconfiguration of 118 bus distribution system

	Simulation results of 69 bus distribution network	
	Before reconfiguration	After reconfiguration
Tie switches :	118 119 120 121 122 123 124 125 126 127 128 129 130 131 132	23 26 34 39 42 51 58 71 74 95 97 109 122 129 130
Power loss :	1298.0861 kW	869.7271 kW
Power loss reduction:	-	32.9993 %
Minimum voltage :	0.8698 pu	0.93229 pu

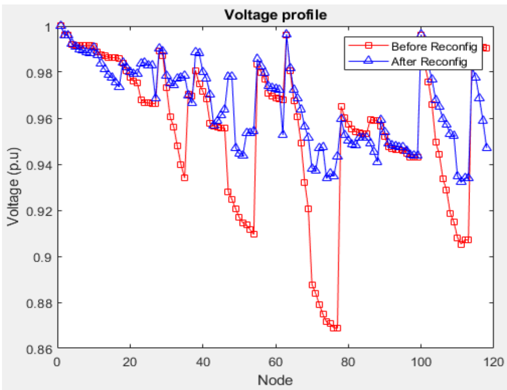


Figure 7. Voltage profile of each bus before and after reconfiguration (118 bus system)

Table 8. Comparing results with other heuristic methods

Heuristic method used in 118 bus case	Before reconfiguration	After reconfiguration
Fireworks Algorithms (FWA) [6]	P_{loss} = 1298.09 kW V_{min} = 0.8688	P_{loss} = 854.06 kW V_{min} = 0.9323
Binary group search [7]	P_{loss} = 1294.3 kW V_{min} = 0.9825	P_{loss} = 806.3 kW V_{min} = 0.9711
Ant colony optimization algorithm [9]	P_{loss} = 1294.3 kW V_{min} = 0.9825	P_{loss} = 865.32 kW
Tabu search algorithm [18]	P_{loss} = 1294.3 kW V_{min} = 0.9825	P_{loss} = 884.63 kW V_{min} = 0.9323
Improved tabu search (ITS) [18]	P_{loss} = 1294.3 kW V_{min} = 0.9825	P_{loss} = 865.86 kW V_{min} = 0.9323
Grey wolf optimizer [5]	P_{loss} = 1297.86 kW V_{min} = 0.8688	P_{loss} = 905.19 kW V_{min} = 0.9323
Whale optimization algorithm (proposed method)	P_{loss} = 1298.09 kW V_{min} = 0.8688	P_{loss} = 877.15 kW V_{min} = 0.9323

6. CONCLUSION

This paper introduces the whale optimization algorithm as a new heuristic technique for reconfiguration of distribution systems. The main advantages of this heuristic method is its simplicity and saving time for solving large size problems as 33 bus system and 69 bus system. The obtained results in 33 bus system are very completive to other heuristic methods applied in this system and WOA is the fast convergent to the optimum. The results in the 69 bus system are less completive to others as the minimum result is 99.94 kW while other heuristic techniques obtain 98.57 kW but the main advantage of WOA still local optimum avoidance and fast convergence. The results in 118 bus system are competitive and close to other heuristic methods as minimum results are 869.7 kW with enhanced minimum voltage profile 0.932 per unit.

REFERENCES

[1] R. S. Rao, K. Ravindra, K. Satish and S. V. L. Narasimham, "Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation," *IEEE Transactions on Power Systems*, vol. 28, no. 1, pp. 317-325, 2013.

[2] A. S. Alvani and S. M. Mahaei, "Reconfiguration of distribution networks with presence of DGs to improving the reliability," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 2, no. 2, pp. 241-247, 2016

[3] R. Sirjani, A. Mohamed, and H. Shareef, "Heuristic optimization techniques to determine optimal capacitor placement and sizing in radial distribution networks: A comprehensive review," *Przeglad Elektrotechniczny*, vol. 88, no. 7a, pp. 1-7, 2012.

[4] S. Mirjalili and A. Lewis, "The whale optimization algorithm," *Advances in Engineering Software*, vol. 95, pp. 51-67, 2016.

[5] R. D. Mohammedi, R. Zine, M. Mosbah, and S. Arif, "Optimum network reconfiguration using grey wolf optimizer," *Telecommun. Comput. El. Control*, vol. 16, no. 5, p. 2428, 2018.

[6] A. M. Imran and M. Kowsalya, "A new power system reconfiguration scheme for power loss minimization and voltage profile enhancement using fireworks algorithm," *Int. J. of Elec. Power and Energy Systems*, vol. 62, pp. 312-322, 2014.

[7] S. Teimourzadeh and K. Zare, "Application of binary group search optimization to distribution network reconfiguration," *International Journal of Electrical Power & Energy Systems*, vol. 62, pp. 461-468, 2014.

[8] Y. M. Shuaib, M. S. Kalavathi, and C. C. Asir Rajan, "Optimal reconfiguration in radial distribution system using gravitational search algorithm," in *Electric Power Components and Systems*, vol. 42, no. 7, pp. 703-715, 2014.

[9] A. Y. Abdelaziz, R. A. Osama, and S. M. Elkhodary, "Distribution systems reconfiguration using ant colony optimization and harmony search algorithms," *Electric Power Compo. and Syst.*, vol. 41, no. 5, pp. 537-554, 2013.

[10] A. Y. Abdelaziz, F. M. Mohammed, S. F. Mekhamer, and M. A. L. Badr, "Distribution systems reconfiguration using a modified particle swarm optimization algorithm," *Electric Pow. Syst. Research*, vol. 79, no. 11, pp. 1521-1530, 2009.

[11] K. S. Kumar and T. Jayabarathi, "Power system reconfiguration and loss minimization for an distribution systems using bacterial foraging optimization algorithm," *Int. J. of Electrical Power & Energy Systems*, vol. 36, no. 1, pp. 13-17, 2012.

[12] R. S. Rao, S. V. L. Narasimham, and M. Ramalingaraju, "Optimization of distribution network configuration for loss reduction using artificial bee colony algorithm," *Int. J. of Electrical, Computer, Energetic, Electronic and Communication Engineerin*g, vol. 2, no. 9, pp. 1964-1970, 2008.

[13] T. T. Nguyen and A. V. Truong, "Distribution network reconfiguration for power loss minimization and voltage profile improvement using cuckoo search algorithm," *Int. J. of Elec. Pow. & Ener. Syst.*, vol. 68, pp. 233-242, 2015.

[14] M. P. Selvan and K. S. Swarup, "Distribution system load flow using object-oriented methodology," *2004 International Conference on Power System Technology, PowerCon 2004*, Singapore, vol. 2, pp. 1168-1173, 2004.

[15] A. Wazir and N. Arbab, "Analysis and optimization of IEEE 33 bus radial distributed system using optimization algorithm," *Journal of Emerging Trends in Applied Engineering*, vol. 1, no. 2, pp. 17-21, 2016.

[16] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "MATPOWER: Steady-state operations, planning, and analysis tools for power systems research and education," *IEEE Trans. on Power Systems*, vol. 26, no. 1, pp. 12-19, 2011.

[17] C. E. Murillo-Sánchez, R. D. Zimmerman, C. L. Anderson, and R. J. Thomas, "Secure planning and operations of systems with stochastic sources, energy storage, and active demand," *IEEE Trans. on Smart Grid*, vol. 4, no. 4, pp. 2220-2229, 2013.

[18] D. Zhang, Z. Fu, and L. Zhang, "An improved TS algorithm for loss-minimum reconfiguration in large-scale distribution systems," *Electric Power Systems Research*, vol. 77, no. 5-6, pp. 685-694, 2007.