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Optimal distribution network reconfiguration to minimization power loss

Mansur Khasanov[1, 2*] , *Salah* Kamel[3], *Jasur* Abdubannaev[4], *Furqat* Nazarov[5], *Abror* Kurbanov[5], and *Urinboy* Jalilov[5]

[1]Chongqing University, Chongqing, China
[2]Tashkent State Technical University, Tashkent, Uzbekistan
[3]Aswan University, Aswan, Egypt
[4]North China Electric Power University, Beijing, China
[5]Jizzakh Polytechnic Institute, Jizzakh, Uzbekistan

Abstract. With the development of industry, population growth, and suburbanization, load demand is constantly increasing from year to year. Overload demand has greatly strained the distribution network (DN), resulting in increased power losses due to the high-power flow. Therefore, it becomes very important to minimize power losses at the DN to maximize the efficiency of the distribution companies. Network reconfiguration is one of the effective methods distribution companies use to minimize losses in the DN. This paper proposes Dingo Optimization Algorithm (DOA) to solve network reconfiguration problems and minimize the DN's power loss. DOA mimics the social behavior of the Australian dingo dog. IEEE-33 bus DN has been used to demonstrate the effectiveness of the proposed method. The obtained simulation results compared with other methods in the literature and comparison showed that the proposed DOA provides better quality solutions than other methods.

1 Introduction

The electricity supply chain consists of a power station, a transmission line, a distribution network (DN) and an end-user. The distribution segments of the chain play an important role in the business segment because it is the last interface between the sector and the end-users. These affects the electricity quality and reliability, energy supplied cost, and any malfunction at the distribution segment pollutes the value chain of the entire energy sector. The DN typically operates in a radial configuration because the radial operation is easy to adjust the voltage compared to the grid, better control the power flow, reduce failures, complex coordination of protection relays [1]. In addition, DNs operate at low voltages and high currents, power losses in the network are high, and voltage regulation is less. In 2018 World Bank published a report. According to this report, only 25 percent of total electricity losses occur in the transmission and substation system, while 75% of total losses occur in the DN [2]. In addition, the large power losses at the distribution segment increase the operating time of power grids and result in higher electricity costs to end consumers. For

* Corresponding author: hasanov6654525@mail.ru

reliable operation of the DN and high-quality service to consumers, it is necessary to improve the efficiency of the DN and reduce operating costs. One of the suitable way to reach this goal is to minimize power losses. Minimization of power loss can be achieved through a variety of methods, including distribution network reconfiguration (DNR), installation of capacitors, optimal distributed generation (DG) placement [3]. Among these available techniques, the DNR is the most efficient method for power distribution operators because it requires less investment, as these distribution utilities allow the use of available resources.

DNR involves changing the network topology by switches, its opening or closing (switching mode) the system's branches to obtain the best radial topological configuration. In 1975, the first DNR algorithm was proposed to minimize power loss [4]. Their algorithm was based on a branch and bound method in which all connecting lines were arbitrarily created into a mesh system. Then the switches opened until the radial configuration had been restored. In [5], a network exchange method was implemented to determine the transfer of the power of a to load from one to another. The essence of the technique is that a closed switch in the circuit replaces an open switch and reduces power losses. A replacement configuration is selected that results in a maximum reduction in losses. However, the main disadvantage of this method is that selecting a pair of switches takes a lot of time, and in addition, the process does not provide an optimal solution with multiple switching options. In [6] used heuristic-based algorithm optimal power flow analysis to minimize DN power losses. In [7] applied the branch exchange method using heuristic configuration techniques to minimize DN power loss and balance the load. A spanning tree is initially created, and the branch exchange technique then examines potential trees. Furthermore, among the various optimization methods proposed by researchers in recent years, power loss can be minimized to solve the network reconfiguration problem, including the Genetic Algorithm (GA) [8], Harmony Search Algorithm (HSA) [9], Network Reconfiguration (NR) method [10], Fireworks Algorithm (FWA) [11], Particle Swarm Optimization (PSO) [12], Ant Colony Search Algorithm (ACSA) [13], Modified Honey Bee Mating Optimization Algorithm (MHBMOA) [14], Plant Growth Simulation Method (PGSA) [15], Modified Tabu Search Method (MTS) [12], Improved Tabu Search Method [16], HyperCube – Ant Colony Algorithm [17], Modified Plant Growth Simulation Method (MPGSA) [18], Salp Swarm Optimization Algorithm (SSOA) [19], Heuristic Algorithm [20], as well as Fuzzy adaptation of evolutionary programming (FEP) [21].

In light of the previous, it is obvious that to minimize power losses in a DN using the network reconfiguration technique, metaheuristic and heuristic methods were usually used by most researchers in the mainstream literature, and there is an increase in interest in nature-inspired algorithms for the network reconfiguration problem. In this paper, the recently developed Dingo Optimization Algorithm (DOA) [22] is proposed to solve the problem of network reconfiguration, which is designed to reduce the active power loss of the system while fulfilling all the operational limitations of the network. The stability of the proposed DOA is confirmed on the standard radial IEEE 33 bus system. Numerical results show that the proposed DOA is accurate and efficient compared to the results available in the recently published literature.

This paper is organized as follows: Section 2 presents methods. Section 3 presents the numerical results and discussion. Section 4 presents the conclusions of this paper.

2 Methods

This part is aimed at minimizing power loss through DNR. The objective function of this paper represents as follows:

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$$Min \quad P_{loss} = \sum_{i}^{N_{br}} R_i \frac{P_i^2 + Q_i^2}{V_i^2} \tag{1}$$

where, *Nbr* is the number of total branches in DN, Ri is *i* branch's resistance, *Vi* is the voltage of *ith* bus, and *Pi* and *Qi* are the active and reactive power at the *ith* bus.

The following constraints must be met in optimization prosses:

a) Power balance constraints

The total power supplied to the network must balance the total demand of the load and the total power loss [19].

$$P_{system} = \sum_{i=1}^{N_{br}} P_{brloss}(i) + \sum_{j=1}^{M} P_d(j) \tag{2}$$

$$Q_{system} = \sum_{i=1}^{N_{br}} Q_{brloss}(i) + \sum_{j=1}^{M} Q_d(j) \tag{3}$$

where, P_{system} and Q_{system} are active and reactive system power, P_{brloss} and Q_{brloss} are active and reactive branch power losses, P_d and Q_d are active and reactive load, M is total bus numbers.

b) Bus voltage constraints

The operating voltage on all network buses must be within the specified minimum and maximum voltage limits [19].

$$V_{\min} \le |V_i| \le V_{\max} \tag{4}$$

c) Branch thermal constraints

All network branches must operate within their heat limits.

$$I_{Bi} \le I_{Bi(rated)} \tag{5}$$

d) Constraints of radial topology

The DN topology must have a radial configuration, and there must be no insulated bus in the network.

$$\begin{aligned} &\det[Bus \quad incidence \quad matrix] = 1 \, or -1 \quad (for \quad radial \quad DN) \\ &\det[Bus \quad incidence \quad matrix] = 0 \quad (for \quad nonradial \quad DN) \end{aligned} \tag{6}$$

Overview of Dingo Optimization Algorithm

The Dingo Optimization Algorithm (DOA) is a recently developed metaheuristic optimization technique [22]. DOA mimics the social behavior of the Australian dingo dog. The technique is inspired by dingo hunting strategies that attack by stalking, group tactics, and scavenging behavior. The location of each dingo in the search space provides a candidate solution to the problem. The DOA algorithm uses two parameters, P and Q. P is a fixed value indicating the algorithm's probability of choosing the hunting or scavenger strategy. If the algorithm selects the hunting strategy, then a fixed Q value indicates its probability of choosing among group attack or persecution strategies. Pseudocode of proposed optimization algorithm as follows [23]:

1) Initialization of parameters

$$Na = round(NaIni + (NaEnd - NaIni) * rand) \quad (7)$$

where, $NaIni$ is a minimum number of dingoes that will attack, $rand$ is a random number between (0,1), $NaEnd$ is a maximum number of dingoes that will attack. It can be calculated as follows:

$$NaEnd = Numberofdingoes / NaIni \quad (8)$$

2) P=0.5, hunting or scavenger strategy's probability
3) Q=0.7, group attack or persecution attack's probability
4) The initial population generation stage

$$x_i^0 \quad U(x_{\min}, x_{\max}) \quad (9)$$

where, $x_{\min,j}$, and $x_{\max,j}$, are the lower and upper limits of the dimension j.

5) while iteration < Max Number of Iterations do
6) If random <P then
7) If random <Q then

$$x_i(t+1) = \beta_1 * \sum_{k=1}^{na} \frac{[\varphi_k(t) - x_i(t)]}{na} - x_*(t) \quad (10)$$

8) else

$$x_i(t+1) = x_*(t) + \beta_1 * e^{\beta_2} * (x_{r_1}(t) - x_i(t)) \quad (11)$$

10) end if
11) else

12) $$x_i(t+1) = \frac{1}{2}(e^{\beta_2} * x_{r_1}(t) - (-1)^{\sigma} * x_i(t)) \quad (12)$$

13) end if
14) Update search agents according to low survival value

$$x_{inew}(t) = x_*(t) + \frac{1}{2}(x_{r_1}(t) - (-1)^{\sigma} * x_{r_2}(t)) \quad (13)$$

15) Survival value can be found as follows:

$$survivalrate(i) = \frac{fitness_{\max} - fitness(i)}{fitness_{\max} - fitness_{\min}} \quad (14)$$

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16) Calculate x_{inew}, the new search agents' fitness value can be found as follows:

$$fitness = objective(x_{inew}) \quad (15)$$

17) If x_{inew} p x_i then

$$x_i = x_{inew} \quad (16)$$

18) end if
19) iteration=iteration + 1
20) end while
21) Display x_i, the best optimal solution
22) end procedure (Table 1)

Table 1. Used parameters and operational constraints.

Parameters	Value
Number of populations	50
Number of iterations	100
$NaIni$	2
Bus system voltage constraints	$0.9 p.u. \leq V_i \leq 1.05 p.u.$

3 Results and discussion

To evaluate and validate the effectiveness of the proposed technique has been tested on the standard 33 - bus DN. To analyse the robustness of the proposed method compared to other optimization methods in the available literature to achieve the objective function. The standard 33 bus is 12.66 kV medium-scale DN that consists of 32 sectionalizing switches labeled 1 to 32, 5 tie switches 33 to 37, 33 buses, and 37 branches with active and reactive power load is 3715 kW and 2300 kVAr, respectively [7]. In the base case (without reconfiguration) network power loss is 2010.98 kW, and the minimum bus voltage is 0.9038 p.u. These sectionalizing switches are open in normal operation mode – *SW1-33, SW1-34, SW1-35, SW1-36, SW1-37*. The initial configuration of 33 – bus DN is depicted in Fig. 1, and the results obtained by the proposed MA for the test system is presented in Table 2.

Table 2. The results obtained by the proposed DOA for the 33-bus system.

Scenario	Items	
Scenario-1 (Base case)	Open switches	*SW1-33, SW2-34, SW3-35, SW4-36, SW5-37*
	Power loss (kW)	210.98
	Minimum voltage (p.u)	0.9038
Scenario-2 (After network reconfiguration)	Open switches	SW1-7, SW2-14, SW3-9, SW4-32, SW5-37
	Power loss (kW)	139.56
	Power loss reduction (%)	33.85
	Minimum voltage (p.u)	0.9379

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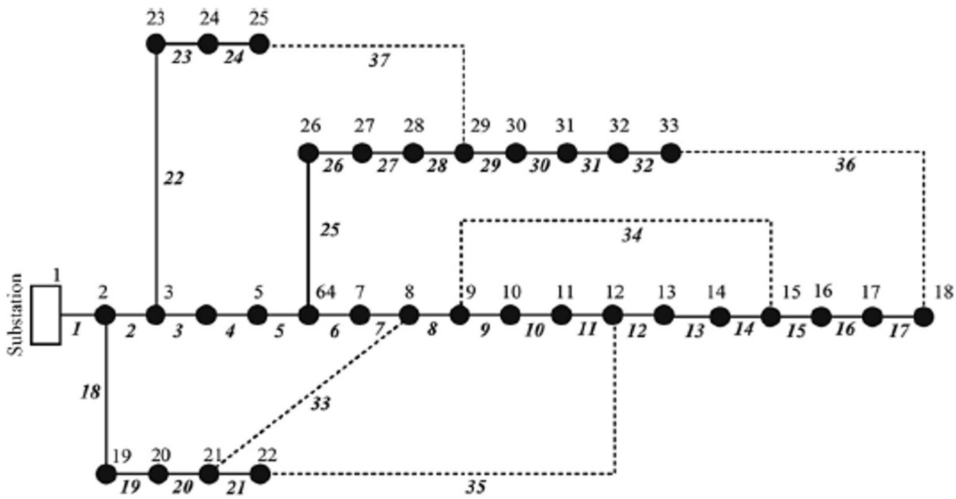

Fig. 1. Initial configuration of IEEE 33-bus DN.

As can be seen from the obtained results in this table, after performing the proposed reconfiguration task based on MA for the IEEE 33 - bus system, switches: SW1-7, SW2-14, SW3-9, SW4-32, SW5-37 are open, and the network power loss is 139.56 kW. The corresponding percentage of power loss reduction for normal load conditions is 33.85%, and the voltage value after reconfiguration increases to 0.9379 pu. A comparison of the results obtained using the proposed method and other methods available in the existing literature is presented in Table 3.

Table 3. Comparison of the results obtained using the proposed method and other methods for the 33-bus system.

Item s/Methods	**OA**	R method [10]	SA [9]	WA [11]	CSA [13]	EB [21]
Ope n switches	W1-7 W2-14 W3-9 W4-32 W5-37	W1-9 W2-28 W3-32 W4-14 W5-7	W1-10 W2-37 W3-36 W4-14 W5-7	W1-7 W2-14 W3-9 W4-32 W5-28	W1-7 W2-14 W3-9 W4-32 W5-28	W1-7 W2-14 W3-9 W4-32 W5-28
Pow er loss (kW)	**39.56**	40.00	42.67	39.98	39.98	39.83
Pow er loss reduction (%)	3.85	0.92	9.67	0.93	0.93	3.79
Mini mum voltage (p.u)	.9379	.9416	.9335	.9413	.9413	/A

A comparative analysis shows that the proposed technique is efficient and effective in reducing DN losses and improving the voltage of the system bus.The voltage profiles before and after reconfiguration are shown in Fig. 2. From the figure, it is clear that the network voltage profile improves with reconfiguration.

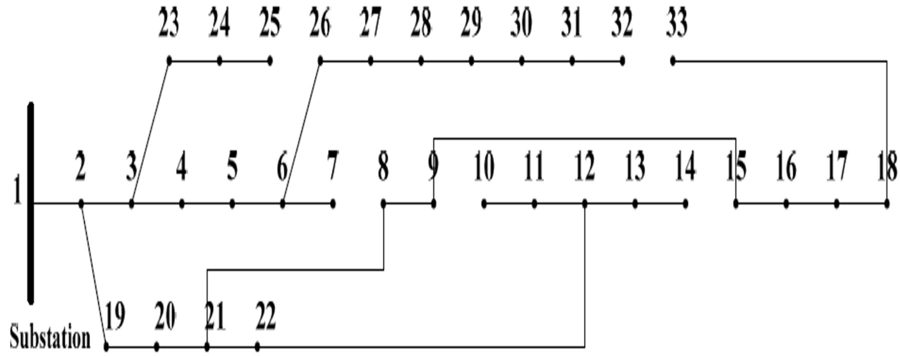

Fig. 2. After optimal reconfiguration of IEEE 33-bus DN.

4 Conclusion

This paper proposed a recently developed Dingo Optimization Algorithm (DOA) for solving the distribution network reconfiguration (DNR) problem for a medium-scale radial distribution network (DN). The proposed technique establishes the optimal network configuration to minimize active power loss, taking into account operational constraints. The standard 33 – bus DN has been considered to validate the efficacy of the presented DOA technique. In addition, the results also show that the proposed DOA provides better quality solutions in reducing power loss and improving the voltage profile compared to other available methods. So, given the above discussion, it can be concluded that the proposed DOA method can be a very promising and powerful approach for dealing with network reconfiguration problems.

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