Reconfiguration of the radial distribution network using an artificial rabbits optimization approach

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ABSTRACT

Lowering system power losses along with improving voltage profile have been major concerns for researchers for the past few decades. The performance of an electrical distribution system (EDS) is dependent on these two factors. This work's main emphasis is on reconfiguring the radial distribution network (RDN) to diminish system power losses and strengthen the voltage profile. The process of network reconfiguration (NR) involves state transitions of sectionalizing and tie switches while still adhering to the limitations. In this work, the optimal reconfiguration network is determined using the artificial rabbits optimization (ARO) approach. The adopted method is tested using IEEE 119 bus RDN under low, normal, and heavy load conditions. When compared to the current approaches, the adopted methodology produced favorable results.

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1. INTRODUCTION

When an electrical distribution system (EDS) fails, network reconfiguration (NR) is performed to reduce the number of de-energised zones while preserving the maximum reliability of the system by operating switching devices remotely or automatically. The techniques did not prioritise power loss reduction through reconfiguration and distributed generation (DG) allocation [1], [2]. The goal of NR with DG is to reduce power losses by optimising network architecture, DG placement, and capacity [3], [4]. NR may be conceptualised as a mixed-integer nonlinear optimising problem, where continuous variables indicate the quantity of electrical power flowing via the system's branches and integer variables reflect the switches current positions [5]–[7]. EDS are evolving rapidly towards active distribution systems in order to improve reliability and standard of service through NR [8], [9]. However, the load demand uncertainties were not considered in [8]. The numerous benefits of NR include mitigated power loss, superior voltage quality, greater distribution of loads, and increased reliability. Simultaneous reconfiguration and DG allocation to reduce power losses were not given top priority in the techniques [10], [11]. The challenge related to service resumption is replicated as a complex programme. The goals are to maximise loads restored while minimising switch operations, while also fulfilling grid operating restrictions and ensuring a radial operation configuration. The uncertainties in load and renewable DGs are not considered in [12], [13].

Managing energy is critical in EDS. An incorrect setting results in higher power loss and low voltage. The EDS should be redesigned in the future to have reduced power loss and higher voltage levels. The proposed methods were evaluated on IEEE 33 radial distribution network (RDN) only [14], [15]. Timely variable load demand complicates distribution network management and control, particularly in high load density zones. A distribution network's power loss will not be minimal with fluctuating load demand for a given network architecture [16], [17]. Concurrent network setup and DG installation in the EDS might diminish true power loss and advance the voltage characteristics. However, these methods did not consider NR at different load levels [18], [19]. NR at constant and variable loads is carried out to improve the efficacy of the EDS. The proposed technique is evaluated only on IEEE 33 RDN [20]. The high-voltage transmission system in a power supply transports the generated electricity to the distribution side's low-voltage users. I^2R loss in a distribution system is considerably higher in comparison to a transmission system [21], [22]. Power system resilience is the capacity of the network to reduce the detrimental effects of rare, unfavorable events. A successful strategy to improve system resilience is to create microgrids with DGs to restore key loads in the distribution system when a significant outage occurs [23]. Real power losses in the EDS are significant, and bus voltages are lower. Optimal capacitor placement and NR strategies are two of the most cost-effective ways to increase voltage profiles and reduce losses while adhering to EDS restrictions [24], [25]. The need for multi-objective NR considering changes in load and DG has grown significantly; this is crucial and necessary to ensure network activities are both secure and effective [26], [27].

The methods used in the previous references take a lot of time, have a low convergence rate, and have a small search space. The recently created meta-heuristic algorithm artificial rabbits optimization (ARO) addresses prior algorithms poor convergence efficiency and limited search capabilities. The ARO algorithm was motivated by the need for rabbits to survive. The algorithm works well and is simple to use. ARO is used in this work with the objectives: i) to obtain an optimally reconfigured network in an IEEE 119 bus RDN, ii) to diminish the true power losses, and iii) to elevate the voltage pattern.

The present study is structured as follows: section 2 formulates the study's problem, the mathematical equations for the suggested method are defined in section 3, and the result evaluation and comparison are shown in section 4. Finally, the research's conclusion is presented in section 5.

2. PROBLEM IDENTIFICATION

ARO is used on an IEEE 119 bus RDN for obtaining an optimally reconfigured network with the least true power losses. Additionally, by diminishing the losses, the voltage levels are improved. The adopted method has an objective function given by (1). Minimization of loss given by:

$$f = \sum_{A=1}^{n} R_A \frac{{P_A}^2+{Q_A}^2}{|V_A|^2} \tag{1}$$

where V_A is the voltage of branch A; the total number of branches is n; P_A, R_A, and Q_A are true power, resistance of the branch, and wattless power.

2.1. Algorithm of adopted method

ARO was used to choose the optimum reconfiguration. The optimum reconfiguration meets all objectives while incurring the fewest losses. On an IEEE 119 bus RDN, ARO is utilised to create an ideally reconfigured network with the fewest real power losses. Furthermore, by reducing losses, voltage levels are enhanced. ARO analyses rabbit behaviours [28].

Algorithm for the adopted ARO method

a. Read the resistance, reactance, and bus load data from the IEEE 119 bus RDN.
b. Set the ARO variables, the maximum iterations, and the population (tie switches) to their initial settings.
c. Develop an arbitrary population of tie switches. Within the switches that are accessible for the IEEE 119 bus RDN, the method arbitrarily selects any switches that will serve as tie switches.
d. Change the system's configuration.
e. Verify if the network has been reconfigured and is radial. If so, calculate fitness (power losses) and select the elite candidate with the lowest losses. Go to step 4 if not.
f. Determine the rabbit energy E using (7). If E >1, perform the exploration phase given by (2)-(6) and update the position of tie switches, or else perform the exploitation phase given by (8)-(12) and update the position of tie switches.
g. After the positioning details of all rabbits (tie switches) have been updated, measure their fitness (losses).

h. Replace the elite if the level of fitness (loss) evaluation is lower.
i. Print the elite (optimal reconfiguration) if the specified iterations have been completed.

3. ARTIFICIAL RABBITS OPTIMIZATION

ARO has been applied to choose the best reconfiguration. The best reconfiguration is the one that achieves all objectives while producing the fewest losses. ARO is used on an IEEE 119 bus RDN for obtaining an optimally reconfigured network with the least true power losses. Additionally, by diminishing the losses, the voltage levels are improved. ARO works by analyzing rabbit behaviors [28]. The phases below explain how the ARO approach searches.

3.1. Detour foraging (exploration)

During foraging, the rabbit chooses to randomly travel to distant locations in search of food, without considering the surrounding environment. It is known as detour foraging, and (2) to (6) show the numerical formulation for it:

$$X_i(t+1) = X_j(t) + A \times (X_i(t) - X_j(t) + round(0.5 \times R_1)) \times n_1 \tag{2}$$

$$A = L \times c \tag{3}$$

$$L = \left(e - e^{(\frac{t-1}{T})^2}\right) \times \sin(2\pi R_2) \tag{4}$$

$$g = randperm\ (D) \tag{5}$$

$$n_1 \sim N(0,1) \tag{6}$$

where: $X_i(t+1) \rightarrow Candidate\ position\ of\ the\ i^{th}\ rabbit\ in\ iteration$ t+1
$X_i(t) \rightarrow Position\ of\ \ i^{th}\ rabbit\ in\ \ iteration\ t;\ X_j(t) \rightarrow Position\ of\ \ j^{th}\ rabbit\ in\ \ iteration\ t$
$b(k) = \begin{cases} 1, & if\ k == g(l) \\ 0, & otherwise \end{cases} \quad k = 1, \ldots.., D\ and\ l = 1, \ldots., [R3\ \times D]$
$L\ \rightarrow running\ length\ of\ the\ rabbits;\ N \rightarrow Denotes\ the\ population\ size;\ D\ is\ Dimension\ size$
$T\ \rightarrow Maximum\ number\ of\ iterations$
The numbers R_1, R_2, R_3, and R_4 are all arbitrary inside the interval [0, 1].

3.2. Exploration to exploitation changeover

During ARO, rabbits frequently participate in random concealment in the latter parts of the hunt, whereas they are more inclined to be involved in persistent detour foraging in the beginning phases of the process. In (7) provides an example of how to use the energy of the rabbit to create a balanced ratio of exploitation to exploration.

$$E(t) = 4\ \left(1 - \frac{t}{T}\right) In\ \frac{1}{R_4} \tag{7}$$

3.3. Random hiding (exploitation)

Predators commonly pursue and harm rabbits. In ARO, a rabbit regularly builds D passages spanning the dimensions of the search region before choosing one at random for concealment in to reduce the danger of being identified. In (8) to (12) provide a mathematical rationale for this behaviour:

$$X_i(t+1) = X_i(t) + A \times (R_5\ \times\ b_{i,r}(t) - X_i(t)) \tag{8}$$

$$b_{i,r}(t) = X_i(t) + H\ \times\ g_r\ (k) \times X_i(t) \tag{9}$$

$$g_r\ (k) = \begin{cases} 1,\ if\ k == [R_6 \times D] \\ 0,\ otherwise \end{cases} \tag{10}$$

$$H = \frac{T-t+1}{T} \times n_2 \tag{11}$$

$$n_2 \sim N(0,1) \quad (12)$$

$b_{i,r}(t)$ depicts the ith rabbit's burrow at random from D burrows. R_5 and R_6 are two random numbers between 0 and 1, and n_2 follows the normal distribution.

4. RESULTS AND DISCUSSION

ARO was used to choose the optimum reconfiguration. The optimum reconfiguration meets all objectives while incurring the fewest losses. On an IEEE 119 bus RDN, ARO is utilized to create an ideally reconfigured network with the fewest real power losses.

4.1. IEEE 119 bus RDN

The conventional IEEE 119 bus RDN is depicted in Figure 1. The true power loss and voltage for the base setup are 1296.57 kW and 0.8688 pu. The ideal reconfiguration that would diminish losses and improve the voltage characteristics is found using the ARO approach. After forming a population (tie switches) at random, the RDN is reconfigured. The chosen approach only provides acceptable configurations that adhere to the bounds and ignores all other configurations. Each reconfigured network's losses are evaluated, and the best choice is the one with the lowest losses.

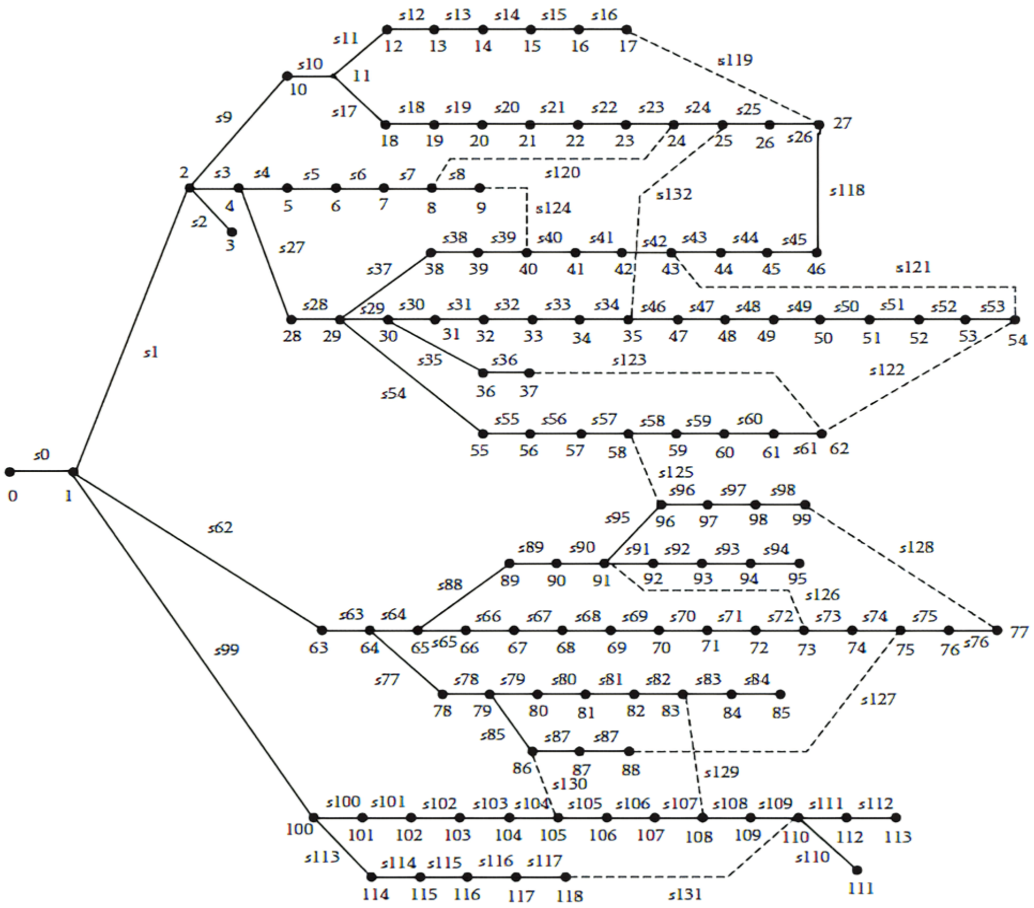

Figure 1. IEEE 119 bus RDN

Table 1 exhibits the findings for the IEEE 119 bus RDN. Table 1 demonstrates that the operation of the tie-switches 23, 43, 120, 51, 122, 61, 39, 95, 71, 74, 97, 129, 130, 109, and 132 is the ideal reconfigured network accomplished by the proposed technique. Real power losses on the 119-bus system were reduced by the adopted technique from 1296.57 kW for the 119-bus RDN's basic configuration to 851.01 kW. Comparing this ideal arrangement to the other possible configurations, the best configuration has the lowest losses, at 851.01 kW. Comparing the suggested approach to existing ones, the per-unit voltage magnitude increased to 0.9412.

Table 1. Outcomes for IEEE 119 bus RDN

Method	Tie switches	Real power loss (kW)	Loss mitigation (%)	Minimal voltage (pu)	CPU time (secs)
Base configuration	118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, and 132	1296.57	NA	0.8688	NA
SSOE [7]	23, 25, 34, 39, 42, 50, 58, 71, 74, 95, 97, 109, 121, 129, and 130	853.6	34.16	0.9323	4.03
MSSOE [8]	23, 26, 34, 39, 42, 50, 58, 71, 74, 95, 97, 109, 121, 129, and 130	854.03	34.13	0.9323	2.52
CGA-ISP [10]	23, 25, 34, 39, 42, 50, 58, 71, 74, 95, 97, 109, 121, 129, and 130	855.04	34	0.929	32.28
Adopted Methodology	23, 43, 120, 51, 122, 61, 39, 95, 71, 74, 97, 129, 130, 109, and 132	851.01	34.36	0.9412	2.41

Figures 2 and 3 illustrate true power loss and the minimum voltage comparison for a IEEE 119 bus RDN. In comparison to the reconfiguration of the IEEE 119 bus RDN utilising the present methods, Figure 2 demonstrates that the adopted method produced the lowest losses. Figure 3 gives the comparison of minimum voltage pu values for the adopted methodology and existing methods. The minimum voltage for the base configuration is 0.8688 pu Besides decreasing the losses, the optimal reconfigured network obtained by the adopted methodology has also enhanced the minimum voltage pu value to 0.9412, which is better than the existing methods. Figure 4 depicts the comparison of node voltages post-reconfiguration for an IEEE 119 bus RDN. From the figure, it could be noticed that the implementation of the adopted method on IEEE 119 bus RDN has shown better voltage levels as compared to previous approaches.

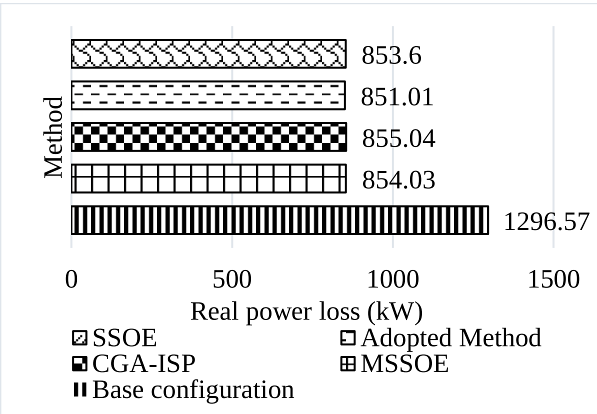

Figure 2. True power loss comparison

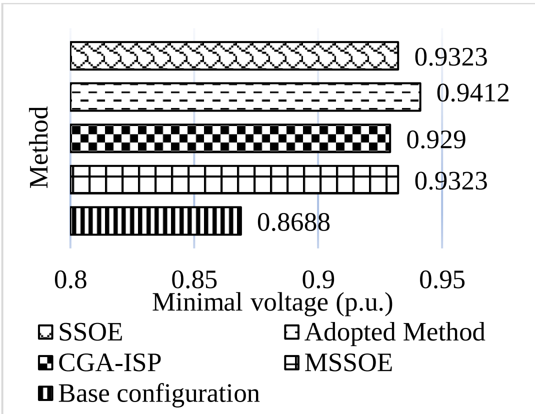

Figure 3. Comparison of minimum voltage

4.2. IEEE 119 Bus RDN at various load levels

The following load levels are examined in order to determine the effectiveness of the adopted method. Scenario 1: light load situation with a 0.5 pu loading. Scenario 2: a normal load state of 1.0 pu Scenario 3: 1.6 pu load (heavy load situation).

The loading status of the IEEE 119 bus RDN under consideration is considered to be light, with a 50% reduction from the typical load. The above system is classified as a normal load while the initial load remains constant. The load on the system rises to 160% of its normal load level, indicating a significant load.

Table 2 displays the results achieved by applying the accepted approach for the IEEE 119 bus RDN under light, normal, and heavy load situations. The true power losses and minimal voltage values of an IEEE 119 bus RDN are compared. The table shows that real power losses are higher when the IEEE 119 bus RDN is highly loaded compared to normal and moderate load situations. When compared to normal and light load situations, the minimum voltage is lower with a high load.

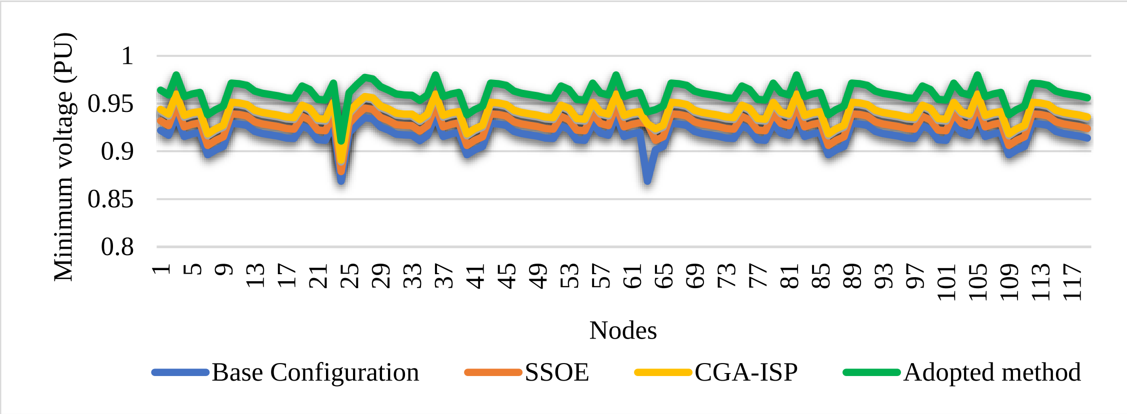

Figure 4. Comparison of node voltages post-reconfiguration

Table 2. Outcomes for IEEE 119 bus RDN at light, normal and heavy loads

Parameter	Base case (light load)	Adopted method (light load)	Base case (normal load)	Adopted method (normal load)	Base case (heavy load)	Adopted method (heavy load)
Tie switches	118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, and 132	23, 43, 120, 51, 122, 61, 39, 95, 71, 74, 97, 129, 130, 109, and 132	118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, and 132	23, 43, 120, 51, 122, 61, 39, 95, 71, 74, 97, 129, 130, 109, and 132	118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, and 132	23, 43, 120, 51, 122, 61, 39, 95, 71, 74, 97, 129, 130, 109, and 132
Real power loss (kW)	324.14	252.75	1296.57	851.01	3630.39	2297.72
Loss mitigation (%)	NA	22.02	NA	34.36	NA	36.71
Minimal voltage (pu)	0.8981	0.9642	0.8688	0.9412	0.8271	0.9123

Figures 5 and 6 show the comparsion of true power loss and minimum voltage levels for an IEEE 119 bus RDN at various load conditions with adopted method. When the IEEE119 bus RDN is heavily loaded, actual power losses are greater than in normal and light load conditions. When compared to normal and light load conditions, the lowest voltage with a high load is lower.

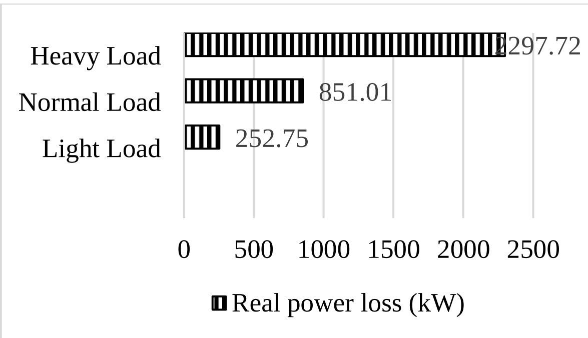

Figure 5. True power loss comparison

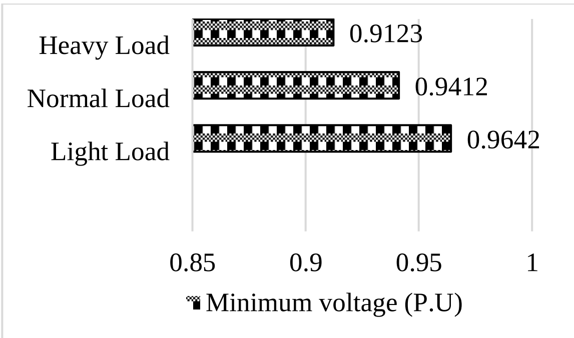

Figure 6. Comparison of minimum voltage

5. CONCLUSION

In this study, a novel technique called ARO is presented to decrease losses while raising voltage in RDN. By using ARO, the ideal reconfiguration is accomplished. IEEE 119 bus RDN is used to evaluate the accomplishment of the adopted method for minimising loss and improving voltage profiles under light, normal, and heavy load conditions. When contrasted to current methods, the implemented methodology has produced superior outcomes regarding loss reduction, a better voltage profile, and reduced computational time. This study will eventually be broadened by looking at the reconfiguration under other hybrid algorithms and network topologies.

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