Artificial rabbits optimization based reconfiguration and distributed generation allotment in the distribution network

**Ganney Poorna Chandra Rao[1,2], Pallikonda Ravi Babu[1,3], Mailugundla Rupesh[4],
Puvvula Venkata Rama Krishna[5]**

[1]Faculty of Electrical and Electronics Engineering Sciences, Visvesvaraya Technological University, Belagavi, India
[2]Department of Electrical and Electronics Engineering, Vignana Bharathi Institute of Technology, Hyderabad, India
[3]Department of Electrical and Electronics Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, India
[4]Department of Electrical and Electronics Engineering, BVRIT Hyderabad College of Engineering for Women, Hyderabad, India
[5]Department of Electrical Electronics and Communication Engineering, GITAM (Deemed to be University), Hyderabad, India

Article Info

ABSTRACT

For the past few years, to reduce system power losses and maintain operating constraints, such as voltage stability, network reconfiguration has been crucial in determining the radial operating framework. Distributed generation (DG) is typically used to generate energy close to the site of consumption. This technology generates energy that is affordable, in contrast to conventional energy production. To lessen energy losses as well as boost voltage characteristics, the adopted methodology is centered on reconfiguration and DG distribution in the radial distribution network (RDN). In this work, the loss sensitivity factor (LSF) is used to determine the right DG position in RDN. After identifying the bus for DG positioning, the artificial rabbits optimization (ARO) technique is used to ascertain the ideal reconfigured network and DG size to lessen energy losses and enhance the voltage profile for RDN. The employed methodology is investigated on IEEE-33 and 69 RDN, respectively, for two cases of considering only reconfiguration without distributing units of DG and reconfiguration with an allotment of three DG units. The latter case showed better results compared to the case of only reconfiguration.

Corresponding Author:

Ganney Poorna Chandra Rao
Faculty of Electrical and Electronics Engineering Sciences, Visvesvaraya Technological University
Belagavi, India
Email: g.poornachandrarao@gmail.com

1. INTRODUCTION

A significant proportion of electricity is lost in a radial distribution network (RDN). A bad voltage profile and unproductive losses in power are the outcomes of inefficient system performance. The system must be appropriately reconfigured to boost efficiency and increase profiles of voltage [1]–[3]. Reconfiguration describes the procedure of changing a switch's state to elevate voltage while cutting losses. The reconfiguration of networks with renewable energy sources is not addressed in these methods [4], [5]. RDN has always had to react to changes in load demand, resulting in voltage oscillations beyond the allowable fluctuation range across multiple buses and losses in power. Distributed generation (DG) must be correctly positioned and scaled for a better profile of voltage and to minimize electrical power losses [6], [7]. Timely variations in load demand in an energy distribution network make operation and management more difficult. With fluctuating load demand and a fixed network structure, the losses in power loss of an RDN will not be at their lowest. Thus, prompt network reconfiguration is necessary. However, this approach does not deal with reconfiguring networks to

include renewable energy sources [8]. An approach incorporating and omitting DGs has been proposed to decrease power losses during reconfiguration. In this strategy, the required search region for each iteration step is changed for reconfiguration. This strategy, however, was unable to handle load uncertainties [9]. Reconfiguration and the erection of DG are frequently employed to lessen losses of power and increase profiles of voltage. The DG's position and size are the primary identifiers in the DG installation [10]–[12].

To handle the challenges of simultaneous reconfiguration, optimal size, and location of DG, hybrid methods were introduced in RDN [13], [14]. An algorithm was deployed for optimum reconfiguration to minimize losses and reinforce the voltage pattern. It modifies an existing network's configuration by combining the divergent properties of particle swarm optimization (PSO) with the heightened effect of genetic algorithms (GA). The adopted technique was only evaluated on an IEEE 33 RDN [15]. A mixed probabilistic model to consider the DGs' power output unpredictability and system demands was proposed. The method did not prioritize reducing power losses through reconfiguration and DG allotment [16]. A unique modified neural network approach is developed to minimize losses in power and increase profiles of voltage [17]. A reconfiguration approach has emerged as a practical technological response for distribution system operators for enabling quick voltage regulation and enhancing systems' overall efficiency [18]–[20].

The factors that lead to the implementation of DGs include the appropriate utilization of electricity production, market liberalization or competition laws, investments in energy sources, quick processing times and lower investment costs of individual plants, and proximity of the generating station to heavy loads that reduce costs [21]–[23]. A novel strategy based on graph theory is suggested for rapid and reliable network reconfiguration. This strategy does not resolve the uncertainty in generation [24]. Numerous governments concur that the main legal justification for the adoption of DGs is their ability to reduce exhaust pollutants. Loss in the RDNs is lowered by executing reconfiguration with DG hosting [25]. The enhanced sine-cosine algorithm (ESCA) for the finest placement of RDN by including reconfiguration and DG has been proven by Raut and Mishra [26]. In order to configure the RDN with the best distribution of numerous DGs, an improved spotted hyena algorithm has been proposed [27]. An RDN operation optimization using mixed particle swarm optimization (MPSO) has been offered by Essallah and Khedher [28] to mitigate loss and boost the voltage in RDN.

The adopted methodology addresses all the limitations of current methods in the preceding paragraphs. artificial rabbits optimization (ARO), a recently developed meta-heuristic algorithm, tackles the shortcomings of previous algorithms' poor convergence efficiency and restricted search capabilities. Combinatorial optimization problems lend themselves very well to this meta-heuristic's technique. It can commonly do so in a reasonable amount of time and with a sufficient response. ARO is employed in this study because of its capacity to locate the global optimal in a relatively limited time frame: i) Reconfiguring the RDN and determining the DGs sizes to address issues with voltage stability and power loss minimization; ii) Loss sensitivity factor (LSF) is exploited to identify the potential bus location for the DG connection; and iii) To assess its effectiveness, ARO has been evaluated against IEEE 33 and 69 RDN.

The investigation is organized in the following manner: i) The problem of this investigation is defined in section 2; ii) Section 3 defines arithmetic equations with the proposed method; iii) The fourth part shows the outcomes and their comparisons; and iv) The final section summarizes the findings of this investigation.

2. PROBLEM FORMULATION

DG sizing and distribution should be approached with caution. Studies suggest that incorrectly sized or positioned DG could result in greater system losses. To mitigate true power losses, various techniques are employed to define the optimum reconfigured network and DG sizes. To accomplish this, LSF and ARO are implemented to locate the right position of the DG, the optimal reconfigured network, and DG sizes. The study's objective function described in (1).

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

Where n represents the entire number of branches, V_A, R_A, Q_A, and P_A are voltage, branch resistance, wattless power and true power of branch A.

2.1. Flow chart of adopted methodology

The primary goal is to reconfigure the RDN to place the DG in the most feasible location and dimensions to lessen losses of power and increase voltage values. To locate potential buses for DG connections, the LSF is used. Using ARO, the ideal reconfiguration network and DG size have been identified. The adopted methodology's work flow is pictured in Figure 1.
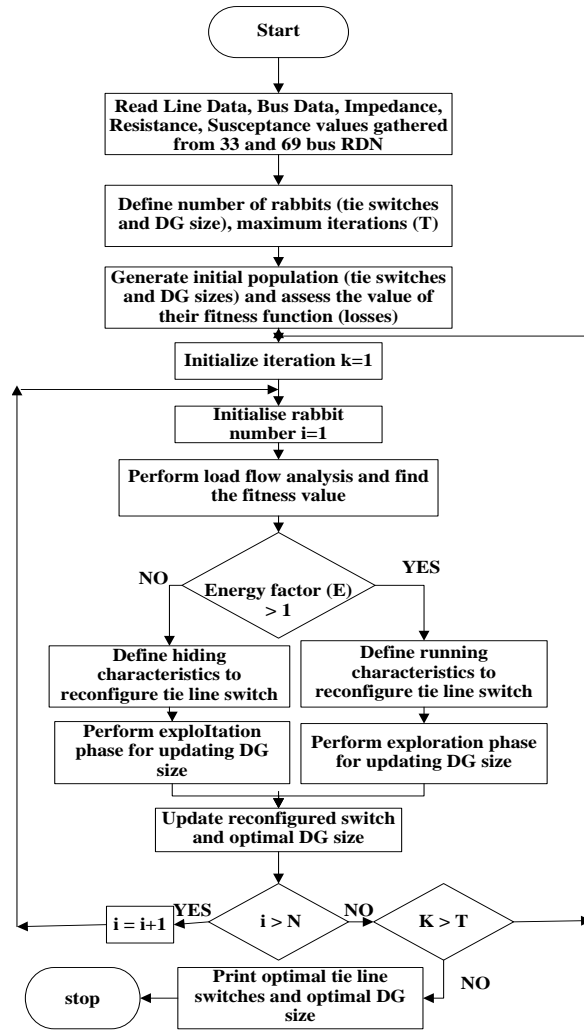
Figure 1. Adopted methodology's workflow

3. PROPOSED METHOD

The major aim is to reconfigure the RDN and obtain the most optimal positioning and size for the DG to mitigate losses in power and boost voltage levels. The LSF is employed to identify prospective bus locations for DG connections. The optimum reconfiguration network and DG size have been determined using ARO. The findings of the adopted methodology are significantly improved when tested on typical IEEE-33 and 69 RDN.

3.1. Loss sensitivity factor (LSF)

The LSF [11] of each bus is calculated by running load flow and sorted in decreasing order. The buses for DG installation must likewise be prioritized in the same manner. The bus with the highest LSF value is given top priority for DG placement. The Ath line, as illustrated in Figure 2, has impedance R_A+JX_A between the A-1 and A buses and is attached to the load P_e+jQ_e.

Active power loss for A^{th} line is given by (2).

$$P_{loss} = \frac{(P_e^2+Q_e^2)R_A}{V_A^2} \tag{2}$$

The LSF can be obtained from load flow analysis using (3).

$$\frac{\partial P_{loss}}{\partial P_e} = \frac{2*P_e*R_A}{V_A^2} \tag{3}$$

Where, V_A is the amplitude of voltage received.

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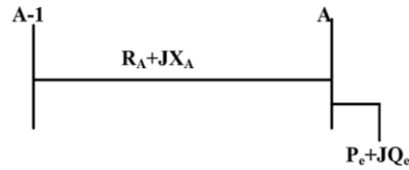
Figure 2. Line from A-1 to A node

3.2. Artificial rabbits' optimization
ARO is employed in this work to determine the best-reconfigured network and DG size. Artificial rabbits optimization (ARO) works based on rabbit behavior [29]. The ARO approach's search procedures are shown in the following stages.

3.2.1. Detour foraging (exploration)
A rabbit will not consume grass close to its nest. The rabbit likes to roam aimlessly to remote regions in quest of food. This is referred to as detour foraging, and it is represented by (4)-(8).

$$X_i(t+1) = X_j(t) + A \times (X_i(t) - X_j(t) + round(0.5 \times R_1)) \times n_1 \qquad (4)$$

$$A = c \times L \qquad (5)$$

$$L = \left(e - e^{\left(\frac{t-1}{T}\right)^2}\right) \times sin(2\pi R_2) \qquad (6)$$

$$g = randperm(D) \qquad (7)$$

$$n_1 \sim N(0,1) \qquad (8)$$

Where:
- $X_i(t+1) \rightarrow$ Candidate position of the ith rabbit in iteration t+1
- $X_i(t) \rightarrow$ Position of ith rabbit in iteration t; $X_j(t) \rightarrow$ Position of jth rabbit in iteration t
- $b(k) = \begin{cases} 1, if\ k == g(l) \\ 0, otherwise \end{cases} k = 1, \ldots, D$ 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; randperm (D) is an arbitrary integer between 1 and D
- R1, R2, R3, and R4 are all arbitrary numbers in the range [0, 1].

3.2.2. The move between exploration to exploitation
In ARO, rabbits often employ randomized concealing in the final phases of the hunt. Although, constant detour foraging is more prevalent in the initial phases of the iteration. The concept of employing rabbit energy to produce a balanced ratio of exploitation and exploration depict in (9).

$$E(t) = 4\left(1 - \frac{t}{T}\right) In \frac{1}{R_4} \qquad (9)$$

3.2.3. Random hiding (exploitation)
In ARO, a rabbit constantly develops D passages across the boundaries of the search space prior to randomly choosing any to stay concealed in to reduce the likelihood of getting captured by predators. The mathematical explanation of this phenomenon is seen in (10)-(14).

$$X_i(t+1) = A \times \left(R_5 \times b_{i,r}(t) - X_i(t)\right) + X_i(t) \qquad (10)$$

$$b_{i,r}(t) = H \times g_r(k) \times X_i(t) + X_i(t) \qquad (11)$$

$$g_r(k) = \begin{cases} 1, if\ k == [R_6 \times D] \\ 0, otherwise \end{cases} \qquad (12)$$

$$H = \frac{T-t+1}{T} \times n_2 \qquad (13)$$

$$n_2 \sim N(0,1) \qquad (14)$$

$b_{i,r}(t)$ depicts the ith rabbit's burrow picked randomly among the D burrows. R_5 and R_6 are arbitrary numerical values from zero and one.

4.   RESULTS AND DISCUSSION

In this research, the implementation for optimum network restructuring and DG sizing is executed. The ARO methodology has been validated for optimum restructuring of networks and sizing of the DG. While LSF is used for finding the optimal DG unit positioning. The adopted methodology has been validated on IEEE-33 and 69 RDN.

4.1. Performance analysis of IEEE-33 RDN

The ARO method is used on the 12.66 KV RDN, termed the IEEE-33 RDN illustrated in Figure 3. To evaluate the effectiveness of the ARO technique, two separate cases of only reconfiguration and reconfiguration with an allocation of three DG units were investigated. In comparison to other solutions for both circumstances, the methodology used has been shown to lower real power losses while boosting minimum voltage levels.

4.1.1. Case 1 (IEEE-33 RDN reconfiguration)

It just involves reconfiguring the 33-RDN, and the results of the ARO strategy are compared to those of the other ways in Table 1. It reveals that the utilized methodology reduced real power losses to 137.06 kW as compared to the base configuration losses of 202.69 kW. The methods used also increased the minimum voltage level to 0.9512, compared to the base configuration's minimum voltage of 0.9107.

4.1.2. Case 2 (IEEE-33 RDN reconfiguration with distribution of three DG units)

Three DG units are distributed during reconfiguration, and the results of the ARO methodology are compared to those of the other approaches in Table 2. It reveals that the utilized methodology reduced real power losses to 57.06 kW as compared to the base configuration losses of 71.46 kW. The methods used also increased the minimum voltage level to 0.9792, compared to the base configuration's minimum voltage of 0.9687.

4.2. Performance analysis of IEEE-69 RDN

IEEE-69 RDN is used to assess the effectiveness of the implemented approach. It is equipped with 68 sectionalized switches and 5 tie lines. The cumulative true and phantom power demands are 3802 kW and 2694 kVAR. Figure 4 illustrates the base configuration of an IEEE-69 RDN.

4.2.1. Case 1 (IEEE-69 RDN reconfiguration)

It involves only reconfiguring the IEEE-69, and the outcomes of the ARO approach are contrasted with those of the other methods in Table 3. It reveals that the utilized methodology reduced real power losses to 97.62 kW as compared to the base configuration losses of 224.95 kW. The methods used also increased the minimum voltage level to 0.9532, compared to the base configuration's minimum voltage of 0.9092.

4.2.2. Case 2 (IEEE-69 RDN reconfiguration with allocation of three DG units)

Three DG units are distributed during reconfiguration, and the results of the ARO methodology are compared to those of the other approaches in Table 4. It reveals that the utilized methodology reduced real power losses to 38.62 kW as compared to the base configuration losses of 69.40 kW. The methods used also increased the minimum voltage level to 0.9894, compared to the base configuration's minimum voltage of 0.9790.
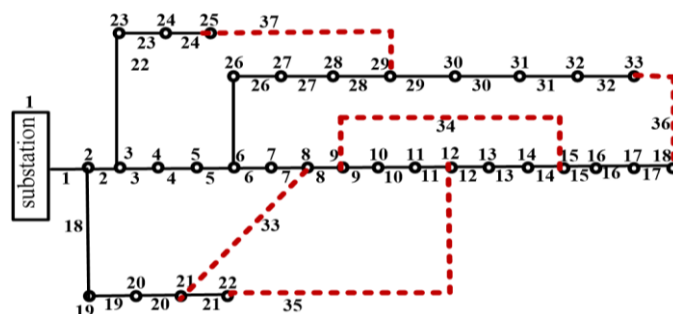

Figure 3. IEEE-33 RDN (base configuration)

Table 1. Investigations for IEEE-33 RDN (only reconfiguration)

Parameter	Base configuration	Modified sequential switch opening and exchange [9]	Advanced cuckoo search algorithm [19]	Harmony search algorithm [21]	Adopted methodology
Tie-switches	33,34,35,36,37	7,9,14,32,37	07,14,9,32,28	7,14,9, 32, 37	7,10,14,37,36
Real power loss (kW)	202.69	139.55	139.98	138.06	137.06
Loss mitigation	NA	31.15%	30.93	31.88	32.3%
Minimal voltage (p.u.)	0.9107	0.9378	0.9413	0.9342	0.9512
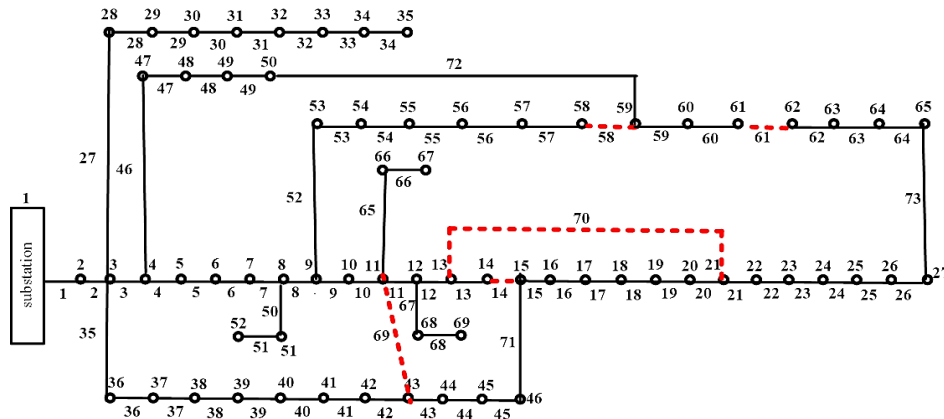
Figure 4. IEEE-69 RDN

Table 2. Outcomes for IEEE-33 RDN (reconfiguration with three DG units)

Parameter	Base configuration	Modified sequential switch opening and exchange [9]	Advanced cuckoo search algorithm [19]	Harmony search algorithm [21]	Adopted methodology
Tie-Switches	33,34,35,36,37	7,9,14,32,37	7,10,13,32,27	7,14,10,32,28	7,14,11,28,32
DG in kW (Bus)	754 (14), 1099.4 (24), 1071.4 (30)	754 (14), 1099.4 (24), 1071.4 (30)	426.3 (32), 1202.4 (29), 712.7 (18)	525.8 (32), 558.6 (31), 584 (33)	580 (21), 618.2 (29) 765.2 (33)
Real power loss (kW)	71.46	57.7	63.69	71.05	57.06
Loss mitigation	NA	19.25%	10.8%	5%	20.1%
Minimal voltage (p.u.)	0.9687	0.9774	0.9786	0.9700	0.9792

Table 3. Investigations for IEEE-69 RDN (only reconfiguration)

Parameter	Base configuration	Modified sequential switch opening and exchange [9]	Advanced cuckoo search algorithm [19]	Harmony search algorithm [21]	Adopted methodology
Tie-Switches	69,70,71,72,73	13,57,61,69,70	69,70,14,57,61	69,18,13,56,61	13,22,52,69,71
Real power loss (kW)	224.95	99.69	98.59	99.35	97.62
Loss mitigation	NA	55.68%	56.16	55.85	56.6%
Minimal voltage (p.u.)	0.9092	0.9428	0.9495	0.9428	0.9532

Table 4. Outcomes for IEEE-69 RDN (reconfiguration with three DG units)

Parameter	Base configuration	Modified sequential switch opening and exchange [9]	Advanced cuckoo search algorithm [19]	Harmony search algorithm [21]	Adopted methodology
Tie-Switches	69,70,71,72,73	13,58,64,69,70	69,70,12,58, 61	69,17,13,58, 61	13,57,61,69,71
DG in kW (Bus)	526.8 (11), 380.4 (18), 1719 (61)	526.8 (11),380.4 (18), 1719 (61)	1749.6 (61), 156.6 (62), 409 (65)	1066.6 (61), 352.5 (60), 425.7 (62)	626.4 (18), 424.7 (60), 525.4 (62)
Real power loss (kW)	69.40	39.64	40.49	40.3	38.62
Loss mitigation	NA	42.88%	41.6%	41.9%	44.3%
Minimal voltage (p.u.)	0.9790	0.9693	0.9873	0.9736	0.9894

5.   CONCLUSION

The current research introduces a unique technique for optimized reconfiguration and positioning of DG that lowers losses while boosting voltages in RDN. For lowered RDN losses, ARO is recommended to resolve the reconfiguration problem and provide the optimal switching pattern. To determine the ideal spot for DG installation, LSF is used. The efficacy of the employed procedure was tested on IEEE 33 and 69 RDN for two cases of considering only reconfiguration and reconfiguration with the allotment of 3 DG units. Case 2 has shown better results for the IEEE-33 and 69 RDN. This investigation may ultimately be broadened by analyzing the reconfiguration under various blended algorithms and network architectures.

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BIOGRAPHIES OF AUTHORS

Ganney Poornachandra Rao is an associate professor at Vignana Bharathi Institute of Technology's Department of EEE. He graduated from Chittoor's Sreenivasa Institute of Technology and Management Studies with a B.Tech. He received an M. Tech. from the Sreenidhi Institute of Science and Technology in Hyderabad. He is now pursuing a Ph.D. in electrical engineering at Visvesvaraya Technological University in Belagavi. He has 15 years of teaching experience and 15 publications in peer-reviewed journals. He can be contacted at email: g.poornachandrarao@gmail.com.

Pallikonda Ravi Babu is a professor at Sreenidhi Institute of Science and Technology's Department of EEE. In 2010, he obtained his Ph.D. from JNTU in Hyderabad. He earned a B.E. in EEE from the University of Mysore in Karnataka., in 1996 and an M. Tech. in power systems in 1999. He has been teaching for 21 years and has had 115 research papers published in international journals and conferences. He supervised two Ph.D. students. At Visvesvaraya Technological University, two more research scholars are pursuing their Ph.D. under his guidance. He can be contacted at email: ravi.dsm@gmail.com.

Mailugundla Rupesh earned a B.Tech. in electrical and electronics engineering from BV Raju Institute of Technology in Narsapur, Andhra Pradesh, in 2010 and an M. Tech. in Power System Control and Automation from Jayamukhi Institute of Technological Sciences in Narsampet, Andhra Pradesh, in 2013. He is pursuing a Ph.D. from Visvesvaraya Technological University in Belagavi, Karnataka, India. He has ten years of teaching experience. Since 2017, he has been working as an assistant professor in the Department of Electrical and Electronics Engineering at the BVRIT Hyderabad College of Engineering for Women in Hyderabad, Telangana, India. He can be contacted at email: m.rupesh1@gmail.com.

Puvvula Venkata Rama Krishna is an associate professor at GITAM (deemed to be university), Hyderabad, Department of EECE. In 2020, he obtained his Ph.D. from JNTU in Hyderabad. He earned a B.E. in EEE from the Osmania University of Hyderabad in Telangana in 2000 and an M. Tech. in power systems from IIT-Roorkee in 2004. He has been teaching for 19 years. He is supervising five Ph.D. students at GITAM (deemed to be university), Hyderabad. He can be contacted at email: rpuvvula@gitam.edu.