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Power Loss Minimization and Grid Stability Enhancement in IEEE 33-Bus Network using African Bison Optimization

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***Abstract*—Power distribution systems, especially radial topologies like IEEE 33-bus network, commonly challenges severe problems such as high-power losses, voltage profile instability, and high voltage drops during peak load periods, primarily due to the high line resistance. Although the aim of Distributed Generation (DG) is to minimize losses and ensure voltage stability, improper placement, and sizing of DG leads to higher losses and inefficient operation. To mitigate these consequences, this work proposes an African Bison Optimization (ABO) for optimal placement and sizing of DG units in the IEEE 33-bus radial distribution system. Specifically, proposed approach utilizes Voltage Stability Index (VSI) to identify proposed buses for DG installation, and ABO accomplished to identify optimal sizes for DG units to minimize real and reactive power losses and maintaining improved voltage profiles. Simulation results demonstrate that the proposed ABO solution performs significantly well at reducing distribution losses while improving the overall voltage stability.**

Keywords—Distributed Generation, African Bison Optimization, Voltage Stability Index, IEEE 33-bus network.

I. INTRODUCTION

The design of Power Distribution Systems (PDS) is an essential element in electric power system planning [1]. An inadequate design effect in a higher level of power losses, voltage profile issues, and a lower power factor. Among the various approaches for minimizing power losses, Network Reconfiguration (NR) has been the focus of attention because of its low cost and effectiveness [2], [3]. NR involves adjusting the connection and sectionalizing switches' both open and closed states while fulfilling system constraints such as voltage and current [4].

Due to the increasing demand in electrical energy, and longer distance between generation, and consumption points, transmission, and distribution losses have become more of a concern [5]. NR, DG placement, and capacitor placement generally decrease losses and increase stable voltage. Placing DG in optimal locations enhances voltage outline of system and its active power losses [6]. However inappropriate positioning has an adverse effect on the overall system [7]. The IEEE 33-bus radial distribution network often using as a benchmark for testing optimization techniques that are based on power systems [8]. Nevertheless, finding the best network configuration is considered a complicated and constrained combinatorial issue [9-10]. To solve this, researchers have utilized a range of heuristic and metaheuristic optimization techniques namely multi-objective cuckoo search algorithm [11], Ant Colony Optimization (ACO) [12], and Mayfly Algorithm (MA) [13] but these approaches still have drawbacks such as running the risk of premature convergence, slow rate of convergence, local optima traps, and inability to perform well on large or highly constrained distribution network optimization problems. Dalya Ayad et al (2025) have implemented a method combining Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) approach significantly reduces power losses and improves voltage stability, though it is computationally complex due to the nonlinear nature of the reconfiguration process [14]. Mansur Khasanov et al (2023) have developed the Dingo Optimization Algorithm (DOA) for solving the distribution network reconfiguration problem to minimize active power loss. However, it face limitations in convergence speed [15].

This work presents ABO method for optimum DG location and sizing in IEEE 33-bus system, which reduces power losses and improves voltage stability. In contrast to previous methods such as GA, PSO, and Mayfly Algorithm, which suffer from premature convergence and high complexity, ABO displays higher convergence and efficiency when dealing with nonlinear, limited scenarios. Our findings show that ABO outperforms existing approaches in terms of reducing losses and enhancing grid stability, providing a robust and adaptive response to the existing research.

II. LOAD FLOW ANALYSIS

The management of loads is important to development of current power systems. Load flow examination is significant,

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or perhaps crucial, device for dealing with power system operations and management challenges. The present research analysed the electrical system's constant state to estimate the amounts of power, voltage, current, actual power, and reactive power under various loading circumstances. Hence traditional optimization methods based on results and gradients fail to find global optimum. Therefore, heuristic solution methods or algorithms are employed. Mathematical equations that represent active and reactive power

$$V_{K+1} = V_K - I_K Z \tag{1}$$

$$|I_K| = \frac{\sqrt{P_K^2+Q_K^2}}{V_K} \tag{2}$$

$$P_{loss(K,K+1)} = \frac{P_{K+1}^2+Q_{K+1}^2}{|V_{K+1}|^2} * R \tag{3}$$

$$Q_{loss(K,K+1)} = \frac{P_{K+1}^2+Q_{K+1}^2}{|V_{K+1}|^2} * X \tag{4}$$

Reducing system losses while keeping voltage levels in power distribution system as high as is realistically feasible is the basic objective of optimal power flow. The aim as to attain the lowest actual voltages while minimizing losses.

III. Problem Formulation

A. Objective Function

According to voltage values at the buses and other relevant limitations in the system, the objective function, $f(x)$, is made up of two calculations: Reactive power losses are minimized in the second one, but active power losses are minimized in the first. $K, K+1$ is used to compute active and reactive power loss of line.

$$f(1) = P_{T\ loss} = \sum_{k=0}^{n} P_{loss}(K, K+1) \tag{5}$$

$$f(2) = Q_{T\ loss} = \sum_{k=0}^{n} Q_{loss}(K, K+1) \tag{6}$$

B. Constraints System

The constraints that ensure an ideal power flow computation are as follows:

Voltage constraint:

$$V^{min} \le V_{(K,K+1)} \le V^{max} \tag{7}$$

Here, $V_{(K,K+1)}$ denotes voltage magnitude between K and K+1. V^{min} & V^{max} stands maximum and minimum voltage.

Active Power Loss Constraint:

$$P^{min} \le P_{LOSS(K,K+1)} \le P^{max} \tag{8}$$

Here, $P_{LOSS(K,K+1)}$ stands active loss on the line from K to K+1.

Reactive Power Loss Constraint:

$$Q^{min} \le Q_{Loss(K,K+1)} \le Q^{max} \tag{9}$$

Here, $Q_{Loss(K,K+1)}$ denotes reactive power loss in K to K+1.

In IEEE 33-Bus network, ABO method used to minimize power loss and improve grid stability which is discussed below.

IV. Power Flow Optimization Using Africon Bison Algorithm

The African bison is a type an even-toed ungulate from the Bovidae family that has five varieties. Their habitats are diverse and include open grasslands, savannas (water holes), and coastal rain forests. The strongest bison among the herd become the alpha bison and have priority over the other bison to eat best food. It depend entirely on having water to survive, therefore they rarely stray far away from water sources. If they do not have access to water, they repeatedly lay in the muddy pools to maintain their body temperature levels in hot weather. African bison prefer to live near water where they drink and eat. When both water and food are plentiful, they minimize movement and immerse their entire body in water to prevent heat stress. Jousting and mating happen during the time of rain, when the weather is pleasant and food is abundant. Fig. 1 represents flowchart of ABO process in proposed work.

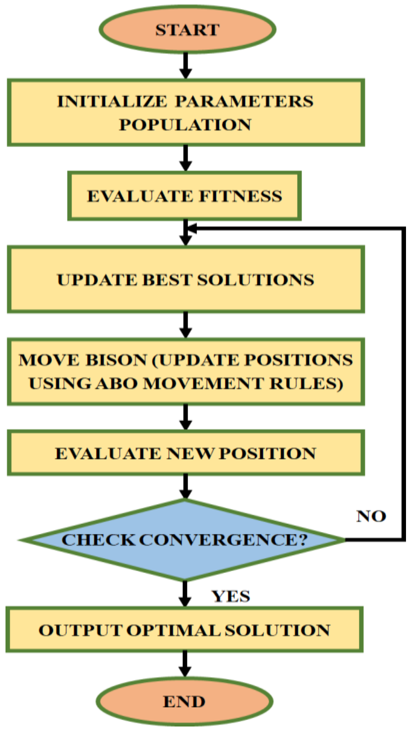

Fig. 1. Flowchart of ABO

***Mathematical Model and Algorithm*:**

Initialization:

Random initialization generates an evenly distributed population, as seen in the equation below.

$$X_i = X_{min} + rand * (X_{max} - X_{min}) \tag{10}$$

Where X_{min} and X_{max} represent the problem's lower and upper bounds, respectively, $rand$ is a random number between 0 and 1, and X_i stands location of the $i-th$ place.

Eq. (11) represents members of bison population with a population matrix where the rows represent solution candidates and the columns represent suggested values for problem variables.

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} x_{1,1} \cdots x_{1,j} \cdots x_{1,d} \\ \vdots \ \ \ddots \ \ \vdots \ \ \iddots \ \ \vdots \\ x_{i,1} \cdots x_{i,j} \cdots x_{i,d} \\ \vdots \ \ \iddots \ \ \vdots \ \ \ddots \ \ \vdots \\ x_{N,1} \cdots x_{N,j} \cdots x_{N,d} \end{bmatrix} \tag{11}$$

Here N and d stand size of population and distinct dimension, while X stands population matrix. The $j-th$ dimension of the $i-th$ person is denoted by $x_{i,j}$.

In the ABO metaphor, all a member is represented as a bison and therefore become the solution candidate specific problem. The value of fitness values generated via a vector, in Eq. (12)

$$F = \begin{bmatrix} F_1 \\ \vdots \\ F_i \\ \vdots \\ F_N \end{bmatrix} = \begin{bmatrix} F(X_1) \\ \vdots \\ F(X_i) \\ \vdots \\ F(X_N) \end{bmatrix} \quad (12)$$

where $i-th$ individual's fitness value is denoted by F_i. These fitness values' vector is denoted by F.

Exploration Phase:

$If\ |S| < Threshold\_1$ (Threshold_1 = 0.5), then they hungry and adjust their movement haphazardly to find food. The male and female subgroups exhibit this behavior, which is described by Eqs. (13) and (14):

$$X_i^{t+1} = (X_{rand}^t * S) + A((X_{max} - X_{min}) * R_1 * R_2^3 \quad (13)$$

$$A = \cos\left(\left(\frac{F_{rand}}{F_i}\right) * R_3\right. \quad (14)$$

Here $R_1$and R_2 represents random numbers between [−1, 1], and X_{rand}^t denotes current position of a random person. A stands bison's capacity. The random and current fitness values are denoted by F_{rand} and F_i, respectively. A random number between [−5, 5] is R_3.

Depending on the temperature level Q, the bison will bathe, joust, mate, and eliminate if $|S| \geq Threshold\_1$, which indicates that food and water are sufficient. Food and water are sufficient if $Q \geq Threshold\_2$ ($Threshold\_2 = 0.6$), the male and female subgroups Eqs (15) model this behavior, which is known as bathing behavior:

$$X_i^{t+1} = 2 * (X_{Gbest}^t - X_i^t) * R_4 + exp(R_5 * Q^5) * cos(Q * 2\pi) \quad (15)$$

Here X_{Gbest}^t denotes best position in herd, R_4 and R_5 represents random numbers between [0, 2]. Eqs. (16) depict mating behavior of male bison.

$$X_{i\_m}^{t+1} = X_{i\_m}^t + \sin(2\pi * R_8) * R_8 * MM * (X_{i\_m}^t - X_{i\_f}^t \quad (16)$$

The following statements are used by female bison to accomplish their mating behavior:

$$X_{i\_f}^{t+1} = X_{i\_f}^t + \cos(2\pi * R_9) * R_9 * MF * (X_{i\_f}^t - X_{i\_m}^t \quad (17)$$

Here $MM\ and\ MF$ stands mating of male & female and $R_8\ and\ R_9$ represents random number.

The elimination conduct shows that the elderly or injured people deliberately disassociate themselves from the group; as a result, the population as a whole maintains its highest degree of competence. This behavior is described by Eq. (18) as follows:

$$X_{worst}^t = X_{min} + R_{10} * (X_{max} - X_{min}) \quad (18)$$

Where the removal of elderly or disabled people from the population is represented by X_{worst}^t. A random number between 0 and 1 is R_{10}.

IEEE 33-Bus Distribution System:

In original state, IEEE 33-bus Fig. 2 has significant active and reactive power losses and indicates substantial voltage decrease at some buses, which demonstrates the necessity for optimal reinforcements. The ABO algorithm obtains the correct locations and sizes of both capacitors and units, within the IEEE 33-bus network. By placing capacitors, voltage profile of system is improved, capacitors provide reactive power to improve voltage stability, especially in buses with low voltage stability. By placing DG units such as solar PV, the performance in the system is further improved as it injects real and reactive power into the system locally, resulting in reduced load on the upstream feeders and lowering losses in the system. While both capacitor placement and DG placement improve power losses and voltage stability, placing both optimally, using the ABO algorithm, provides greater gains than either option alone. The combined optimal placement of these technologies improves voltage support at all buses while providing a more efficient power delivery in IEEE 33-bus system.

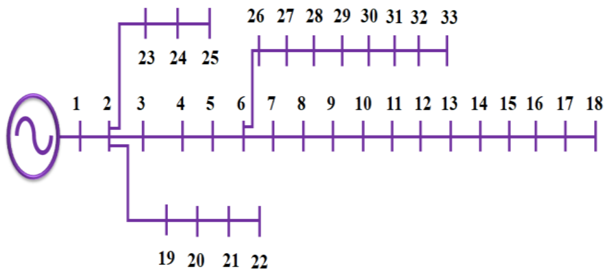

Fig. 2. Diagram of IEEE 33 bus system

This work demonstrates that ABO algorithm is a useful and powerful tool for optimizing reinforcement strategies in radial distribution systems, improving reliability, reducing losses, and improving overall voltage stability.

V. TEST SIMULATION AND RESULT DISCUSSION

In this paper, the ABO algorithm to minimize power losses in IEEE 33-bus system. The results are tested and validated by performing load flow analysis to investigate power loss drop and stable voltage improvements.

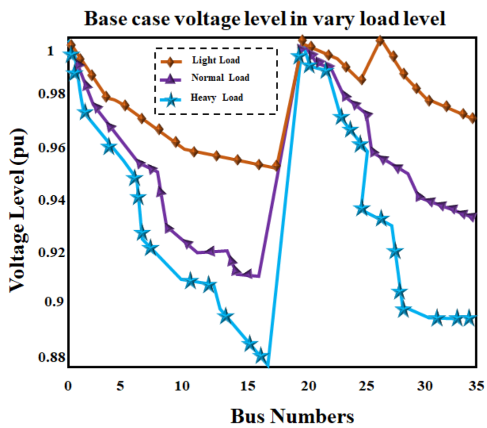

Fig. 3. Voltage profile under varying load condition for 33 bus system

Fig. 3 illustrates voltage delivery under different load circumstances: light, normal, and heavy. Voltage levels decrease progressively as load increases, particularly at the end buses.

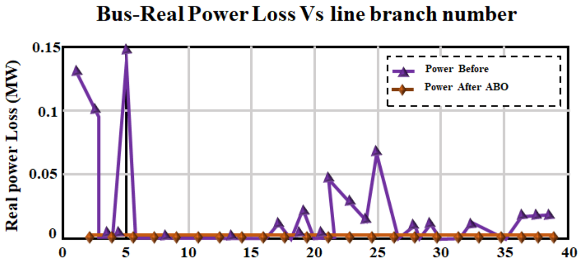

Fig. 4. Real power loss vs branch number in IEEE bus system

Fig. 4 illustrates a comparison of real power loss in branches of IEEE-33 bus system before and after optimization of ABO techniques, clearly demonstrating that power loss significantly reduced afterward through the ABO approach.

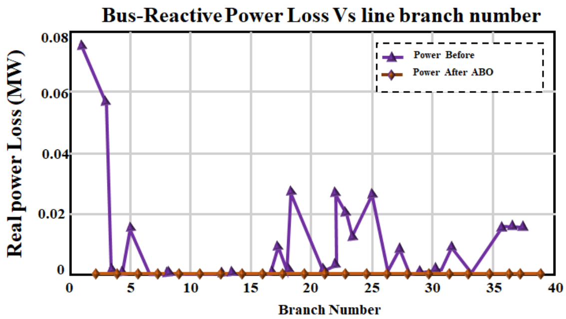

Fig .5. Reactive power loss vs branch number in IEEE bus system

Fig. 5 shows an evaluation of reactive power loss in branches of IEEE-33 bus system before and after optimization of ABO techniques, demonstrating that there is a clear decrease in reactive power loss, particularly after performance of ABO optimized.

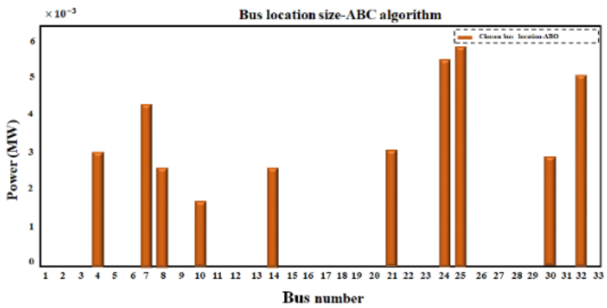

Fig. 6. Location and power for ABO

Fig. 6 illustrates the optimal locations at each bus location of IEEE-33 bus system and power rating when optimized through the use of the ABO approach, selected for the purpose of installing the power to improve the system performance.

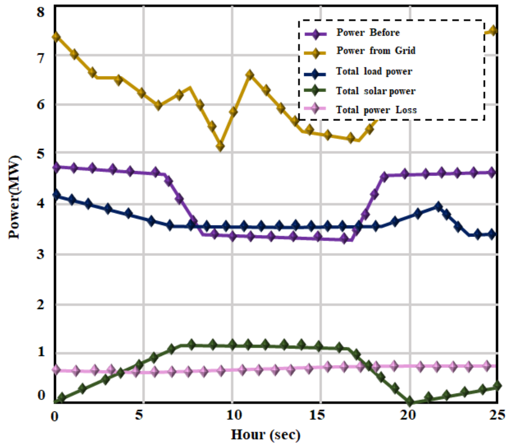

Fig. 7. Comparison of various power flow system

Fig. 7 illustrates the comparison of different power flows in the system through a 24-hour time interval showing the impact of the integration, the variation between grid power and load, solar power on and off the grid power and losses on both scenarios with and without optimized ABO techniques.

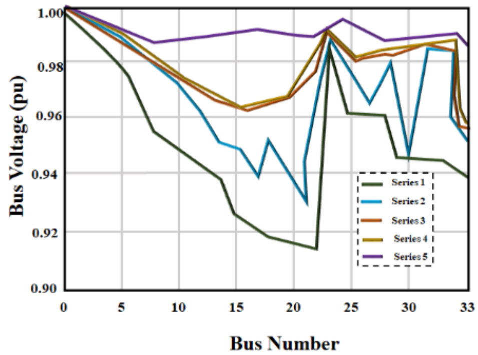

Fig. 8. Bus voltage profile comparison for seven scenarios using ABO in 33 bus system

Fig. 8 displays the profiles of bus voltages of the 33-bus system under seven different scenarios examined using the proposed ABO algorithm. It shows voltage levels examined for each bus in each scenario depending on scenario and thus, shows improved performance under the optimized scenarios.

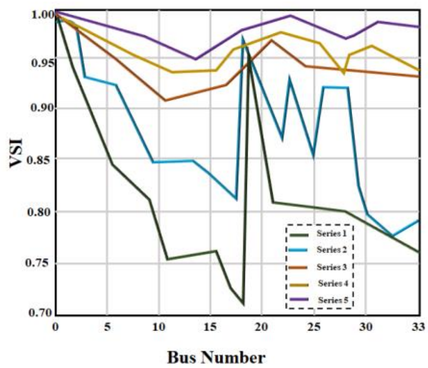

Fig. 9. VSI comparison for seven scenarios in 33 bus system using ABO

Fig. 9 displays the profiles of the VSI of 33-bus system for all seven scenarios examined using the proposed ABO algorithm. It points out improvements in system stability under optimized scenarios.

VI. Conclusion

The present study effectively tackles the essential challenges of power loss and voltage instability using ABO approach. The VSI to determine possible placement of DG on system and ABO methodology is used to determine the optimal capacity at which to operate DG units. It produces a reduction in both real and reactive power losses in IEEE 33-bus system. In addition, for the buses that optimally placed DG, it showed an improvement in voltage profile which contributes to consistency and efficiency of system. Simulation study results demonstrate that the ABO-based approach has predictive capabilities of optimal DG units' size, and it vastly improves, as the possible extension of the methodology for use in modern power distribution system optimization and planning.

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