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Chaotic Artificial Rabbit Optimization to optimize non linear distributed generation penetration considering harmonic distortion

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Chaotic Artificial Rabbit Optimization to optimize non linear distributed generation penetration considering harmonic distortion

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Abstract—This paper introduces a novel optimization problem aimed at determining the optimal number of DGs to maximize the penetration level of distributed generation (DG). The chaotic artificial rabbit optimization (CARO) method, an improved variant of the original ARO algorithm, has been suggested as a solution. The strategy minimizes active power loss by DG units in the best possible locations, with the best power factor and sizes. Several problems, including harmonic distortion from the non-linear currents injected by non-linear DG (NLDG) devices, limit the amount of DG penetration. The IEEE-519 standard specifies these limitations, which include a power balancing equation, bus voltage limits, and individual and total harmonic distortion limits. On the RDN 118 bus, this suggested method has been tested. The results of CARO have been contrasted with those of the regular ARO algorithm and other techniques found in the literature.

Index Terms—NLDG, total harmonic distortion (THD), Active Power Loss (APL), chaotic artificial rabbit optimization (CARO), voltage profile.

I. INTRODUCTION

Rapid industrialization and population growth are driving a steady increase in energy demand. Traditional power generation methods, such as hydroelectric and thermal systems, struggle to meet this growing demand. This imbalance between power supply and demand has led to adopting distributed generation (DG) as a viable alternative. According to the Department of Energy (DOE), distributed generation refers to power generation from energy sources with capacities typically ranging from a kilowatt (kW) to tens of megawatts (MW) per unit. DG systems address the limitations of conventional centralized power generation by providing localized and efficient energy solutions [1]. Distribution networks (DNs) are essential to deliver electricity from substations to consumers. Their high R/X ratio and radial or poorly meshed design frequently lead

to low voltage profiles and high line losses [2]. The use of renewable energy sources such as PV cell, wind in Distributed Generation (DG) technology has several advantages. The optimal position and size of DG can decrease line losses improve voltage profile and also benefit for environment [3]. There are four types of DG.

Type-I: Injects active power at a unity power factor, e.g., photovoltaic (PV) systems.

Type-II: Operates at zero leading power factor, generating only VAR, e.g., synchronous condenser, capacitors.

Type-III: Supplies both real and reactive power, e.g., doubly-fed induction generators in wind turbines.

Type-IV: Delivers real power while absorbing reactive power, e.g., induction generators in squirrel cage wind turbines.

To minimize the line loss and improve the power quality, it is crucial to ensure the proper placement and appropriate sizing of the device. Many studies have been done to get the appropriate position and capacity of DG lowering the line loss and improving the voltage profile. To solve the DG allocation problem, the stochastic fractal search algorithm (SFSFA) has been presented in [4] considering the improvement of voltage stability index, voltage profiles, and minimizing active power loss. Radial distribution networks (RDNs) with 33, 69, and 118 buses have been used to test the method. A mathematical expression using the exact loss equation to determine the optimal capacity of DG units has been developed in [5]. Additionally, teaching-learning-based optimization (TLBO) [6], quasi-oppositional TLBO (QOTLBO) [6], comprehensive TLBO (CTLBO) [7], and Enhanced Search Group Algorithm (ESGA) [8] have been utilized to address the problem with similar objectives. Integrating photovoltaic (PV) systems into

power networks has both benefits and challenges, particularly due to harmonic distortions from inverters. Higher PV-DG penetration can cause excessive total harmonic distortion (THD) at the point of common coupling (PCC). Utilities must address technical constraints to maintain power quality standards during PV-based DG integration [9]. A multi-objective using weighted-sum method has been used to identify the ideal placement and dimensions of solar PV-DG, and a PSO algorithm has been applied in [10]. The impact of DG allocation is evaluated by considering harmonic distortion for non-linear DG. The THD and IHD must be maintained specified 5% and 3% respectively as per IEEE 519 [11]

After analyzing the existing literature, it is evident that most optimization methods face challenges such as low accuracy, poor convergence rates, local optima trapping, and difficulty in solving high-dimensional problems. To overcome these limitations, a newly developed Artificial Rabbit Optimization (ARO) method and its improved variant, Chaotic Artificial Rabbit Optimization (CARO), have been applied to the proposed power system. The integration of chaotic maps enhances the search process by preventing premature convergence, increasing solution diversity, and ensuring faster convergence to the global best solution. In this study, chaotic artificial rabbit optimization (CARO) algorithm has been developed to enhance the global search ability of standard artificial rabbit optimization (ARO) by incorporating Chaotic Local Search (CLS). The optimal number of DG units for maximizing penetration and minimizing active power loss in RDNs has to be identified using CARO. Although it has frequently been ignored in earlier research, harmonic distortion is an important consideration for inverter-based distributed generation (DG) that is nonlinear DG (NLDG). By adding penalties for total harmonic distortion (THD) to the active power loss formulations, this study fills this gap. This is tested for different types of DG (type 1, type 3) on 118 RDN.

II. OBJECTIVE FUNCTION

1) *Minimization of active Power loss (APL)*: In a RDN, active power loss (P_l) throughout networks has been as follows:

$$P_l = \sum_{l=1}^{N_{br}} R_l I_l^2 \quad (1)$$

The objective function is as follows

$$OF_1 = \min \left(\frac{P_{l_withDG}}{P_{l_withoutDG}} \right) + \text{Penalties} \quad (2)$$

Where, R_l , I_l and N_{br} stand for the branch resistance, the branch current of l^{th} and the total number branch respectively of RDN.

$$\begin{aligned} \text{Penalties} = & K_1 \sum_{n=1}^{bus} [\max(0, (V_n - 1.05)) + \max(0, (0.95 - V_n))] \\ & + K_2 \sum_{n=1}^{bus} \max(0, (THD_n - THD_{max})) \end{aligned} \quad (3)$$

Where k_1 and k_2 are penalties factor. The bus voltage V_n , and THD must be maintained within a specific range to

ensure system stability. The minimum and maximum allowable bus voltage levels are typically 0.95 and 1.05 per unit (p.u.), respectively [4], [6]. The maximum allowable THD (THD_{max}) is 5% as per IEEE 519 standards [11]. To prevent the optimization process from choosing impractical solutions, penalty multipliers are utilized to penalize the objective function. Their values are chosen to be significantly high so that any violation of the set limits results in a substantially increased objective function value, thereby guaranteeing the selection of a feasible solution as the optimal one [13]- [14]. Excessively high values can dominate the objective function, potentially hindering convergence. In this case, k_1 and k_2 are set to 10^5 and 10^3 respectively.

A. Constraints:

1) *Power Balance Constraint*:: Equations (4) and (5) ensure the stability of the input and output power relationship. Where

$$P_{SLACK} + \sum_{m=1}^{N_{DG}} P_{DG,m} = \sum_{n=1}^{bus} P_{D,n} + \sum_{k=1}^{N_{br}} P_{l,K} \quad (4)$$

$$Q_{SLACK} + \sum_{m=1}^{N_{DG}} Q_{DG,m} = \sum_{n=1}^{bus} Q_{D,n} + \sum_{k=1}^{N_{br}} Q_{l,K} \quad (5)$$

2) *Bus voltage constraints* [4], [6] :

$$0.95 \leq V_n \leq 1.05, n=1, \dots, bus \quad (6)$$

3) *DG sizing limits*:

$$P_{DG}^{\min} \leq P_{DG,i} \leq P_{DG}^{\max}, i=1, \dots, N_{DG} \quad (7)$$

4) *Power factor limit*:

$$pf_{DG}^{\min} \leq pf_{DG,i} \leq pf_{DG}^{\max}, i=1, \dots, N_{DG} \quad (8)$$

5) *Total harmonic distortion* :

$$THD_i(\%) = \frac{\sqrt{\sum_{h=2}^{h_{max}} |v_{i,h}|^2}}{v_i^{(1)}} \times 100\% \leq 5\% \quad (9)$$

$$IHD_i(\%) = \frac{v_{i,h}}{v_i^{(1)}} \times 100\% \leq 3\% \quad (10)$$

III. SYNOPSIS OF THE ARO

The Artificial Rabbit Optimization (ARO) method is a metaheuristic inspired by nature that simulates rabbit survival tactics to solve challenging optimization issues. Its fundamental elements are 1) Detour Foraging, 2) Random Hiding, and 3) Energy Factor. Detour foraging is a local search strategy; in which rabbits investigate areas near their nests to refine solutions while avoiding predators. Random hiding simulates a global search by allowing rabbits to move to distant territories, promoting diversity, and preventing premature convergence to local optima. The ability of a rabbit to search is determined by its energy factor, making it easier to move from exploration (random hiding) to exploitation (detour foraging), ensuring optimal search [15]

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