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A new improved adaptive imperialist competitive algorithm to solve the reconfiguration problem of distribution systems for loss reduction and voltage profile improvement

Seyed Hasan Mirhoseini [a,*], Seyed Mehdi Hosseini [b], Mehdi Ghanbari [c], Mehrdad Ahmadi [d]

[a] Department of Electrical Engineering, Saveh Branch, Islamic Azad University, Saveh, Iran
[b] Department of Electrical Engineering, Noshirvani University of Technology, Babol, Iran
[c] Department of Electrical Engineering, Semnan Branch, Semnan University, Semnan, Iran
[d] Department of Electrical Engineering, Jouybar Branch, Islamic Azad University, Jouybar, Iran

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ABSTRACT

In this paper, a reconfiguration methodology based on a novel improved adaptive imperialist competitive algorithm (IAICA) is proposed for the sake of minimizing real power losses and enhancing the voltage profile. Unlike ICA, an inherently continuous algorithm reconfiguration is a discrete nonlinear optimization problem. Therefore, the mapping strategy is used to adapt ICA to the reconfiguration problem. Furthermore, a heuristic prohibited zone method is proposed to enhance the exploration capability and converging behavior of ICA. This heuristic method is considered to check the radiality constraint. In addition to IAICA, two other algorithms – GA and ACO – are implemented for reconfiguration of 33 and 69-bus test systems with and without DG. The efficiency of IAICA is validated by comparing the obtained results with each other.

1. Introduction

Most Distribution networks have a meshed structure which is normally operated as a radial to facilitate their protection. Two types of switches are used in primary distribution systems:

The first is sectionalizing switches that exist between each section of an individual feeder and second is tie switches that connect sections of different feeders. These two types of switches are designed for both protection and reconfiguration management.

Reconfiguration is done by changing the topology of distribution systems by altering the open/closed status of switches to transfer loads from heavily loaded feeders to lightly loaded ones and, therefore, power loss may be reduced. This transfer caused loss reduction and voltage profile improvement along feeders. These two factors are known as the objective functions of the reconfiguration problem.

From an optimization point of view, network reconfiguration is a nonlinear mixed integer optimization problem. The fundamental requirement is determining the optimal status of switches in order to minimize power losses and voltage profile index separately while satisfying the technical operational constraints. In this case, the constraints are usually divided into four categories which are related to bus voltage limitation, feeder thermal capacity, isolation nodes, and radial network.

The first research in reconfiguration distributed network has been done for loss reduction by Merlin and Back, based on a branch-and-bound-type optimization by a spanning tree structure [1]. Then, many researches were performed on network reconfiguration with different techniques, algorithms and purposes. Some heuristic techniques were presented for feeder reconfiguration, such as the method that proposed an interesting heuristic algorithm by Shirmohammadi and Hong [2]. In this method, at first, all switches are kept closed. Then, these switches open one by one, in order to handle an optimum power flow in the network. Civanlar et al. has proposed another heuristic algorithm based on the branch exchange [3]. Then, Baran and Wu improved this method [4]. An improved mixed-integer linear program has been presented for determining the tree of minimum active power losses in balanced large medium voltage systems [5]. González et al. solved the reconfiguration problem in medium voltage large-scale distribution networks with a heuristic strategy [6]. In Ref. [7], a sequential switch opening method based on the branch power flow was proposed for minimum loss feeder reconfiguration. Also, an

* Corresponding author. Tel.: +98 111 32 11056.
E-mail address: hasan.mirhoseini@yahoo.com (S.H. Mirhoseini).

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efficient heuristic algorithm for reconfiguration based on branch power flows direction has been presented by Mena and García [8]. Arun and Aravindhababu presented a new reconfiguration algorithm that enhances voltage stability and improves the voltage profile [9]. Some other researches have been done with different intelligent algorithms to achieve considered purposes [10–22]. In Refs. [10,11], Modified simulated annealing technique was applied to network reconfiguration for loss reduction in distribution systems. Furthermore, some new methods based on a fuzzy mutated genetic algorithm for optimal reconfiguration of radial distribution systems were presented [12–14]. The differential evolution algorithm was presented for solving the network reconfiguration for achieving specific purposes [15,16]. In [17], a trained artificial neural network was used to determine the optimum switching status of the switches along the feeders of the network. The training-sets for the ANN were generated by varying the constant P–Q load models. Furthermore, a genetic algorithm and a theoretical approach based on the graph and Matroid theories in order to enhance its ability to explore the solution space were considered for loss reduction [18]. Moreover, Cebrian and Kagan presented a computational implementation of the genetic algorithm in order to tackle the problem of reconfiguring radial distribution systems with considering power quality indices due to voltage sags, using the Monte Carlo simulation method [19]. A reconfiguration methodology based on an Ant colony algorithm was presented to achieve the minimum power loss and increase the load balance factor of radial distribution networks, taking into account the distributed generators' effects [20]. Also, the ant colony optimization was used to solve reconfiguration problems using a multi-objective function with fuzzy variables considering both objectives of load balancing and loss reduction in the feeders [21]. In [22], an algorithm based on fuzzy multi-objective approach was presented for network reconfiguration that load balancing, minimum deviation of the nodes voltage and minimize the power loss was considered as purposes. Recently, some new proposed algorithms have been used to solve reconfiguration problem with new heuristic method for satisfying radial constraint [23–27]. In [23], Sathish Kumar and Jayabarathi presented a method based on bacterial foraging optimization algorithm for distribution network reconfiguration with the objective of loss minimization. Hooshmand and Soltani presented the nelder mead algorithm combined with a bacterial foraging algorithm based on a fuzzy multi-objective function to solve the reconfiguration problem [24]. In Ref. [25], a heuristic harmony search algorithm was used to solve reconfiguration problem in presence of DGs. A genetic algorithm developed based on the edge window decoder encoding technique was used in order to explore the search space for power distribution system reconfiguration with minimal losses [26]. In [27], A new codification was used to deal with large scale networks to satisfy all constraint after reconfiguration with minor computations.

Furthermore, the effectiveness of the presence of distributed generators is an interesting topic that has been intensively researched in recent years [28,29]. Different objective functions have been considered for obtaining effectiveness of presence of DGs in these researches.

In this paper an ICA based meta-heuristic methodology, (introduced by Atashpaz-Gargari and Lucas in 2008 [30]) is proposed to solve the feeder reconfiguration problem, in presence of DGs. Therefore, the main contributions are a new modified algorithm that has excellent exploration capability and the new heuristic method that, always, generates radial configurations after the implementation of the algorithm operator. It is necessary to mention that, we just focus on positive effectiveness of DGs in loss reduction and voltage profile improvement. Therefore, the limitations of applying DGs are not our main purpose.

2. Problem formulation

The purpose of distribution network reconfiguration is to find a radial operating structure that minimizes both real power loss and voltage profile while satisfying operating constraints. Reconfiguration problem can be expressed as a nonlinear optimization problem. The first objective function is real power loss which is formulated as follows:

$$\min LP_{loss} = \sum_{l=1}^{n_b} r_l \frac{P_l^2 + Q_l^2}{V_l^2} \quad (1)$$

where n_b, r_l, P_l, Q_l, V_l are total number of branches, resistance of branch l, active power of branch l, reactive power of branch l, and voltage of the head node of branch l respectively.

Subject to:

(1) Radial network constraint:

The distribution network should be composed of radial structure operation.

(2) Node voltage constraints

$$v_{\mathrm{imin}} \leqslant v_i \leqslant v_{\mathrm{imax}} \quad (2)$$

v_{imin}, v_{imax} are the minimum and maximum voltage limits for node i, respectively.

(3) Branch current constraints:

$$i_\ell \prec i_{\ell\max} \quad (3)$$

Current magnitude of each branch (feeder, laterals and switches) must satisfy permissible ranges.

(4) Isolation constraint:

All nodes must be energized.

The second objective function related to voltage profile index can be expressed as

$$\mathrm{Min}\, V_s = \sqrt{\frac{1}{m_b}\sum_{i=1}^{m_b}(v_i - v_p)^2} \quad (4)$$

$$v_p = \frac{1}{m_b} \times \sum_{i=1}^{m_b} v_i \quad (5)$$

where V_S is the voltage profile index, v_i is the voltage of node i, m_b is the number of nodes and v_p is the average voltage of the node.

3. Imperialist competition algorithm

Imperialist competitive algorithm (ICA) is a new evolutionary algorithm that is inspired by the human's socio-political evolution. Each individual of the population is called country. The population is divided into two groups, colonies and imperialist state. The competition among imperialists to take possession of the colonies of each other forms the core of this algorithm. In this competition the weak empires collapse gradually and finally there is only one imperialist that all other countries are its colony.

3.1. Initialization

This algorithm like other evolutionary ones starts with an initial random population called countries. For creating imperials, some of the best countries in the population selected are considered