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Distribution network reconfiguration for power loss minimization and voltage profile improvement using cuckoo search algorithm

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ABSTRACT

This paper proposes a reconfiguration methodology based on a cuckoo search algorithm (CSA) for minimizing active power loss and the maximizing voltage magnitude. The CSA method is a new meta-heuristic algorithm inspired from the obligate brood parasitism of some cuckoo species which lay their eggs in the nests of other host birds of other species for solving optimization problems. Compared to other methods, CSA method has fewer control parameters and is more effective in optimization problems. The effectiveness of the proposed CSA has been tested on three different distribution network systems and the obtained test results have been compared to those from other methods in the literature. The simulation results show that the proposed CSA can be an efficient and promising method for distribution network reconfiguration problems.

Introduction

The distribution network transfers the electrical energy directly from the intermediate transformer substations to consumers. While the transmission networks are often operated with loops or radial structures, the distribution networks are always operated radially. By operating radial configuration, it significantly reduces the short-circuit current. The restoration of the network from faults is implemented through the closing/cutting manipulations of electrical switch pairs located on the loops, consequently. Therefore, there are many switches on the distribution network. Distribution network reconfiguration (DNR) is the process of varying the topological arrangement of distribution feeders by changing the open/closed status of sectionalizing and tie switches while respecting system constraints upon satisfying the operator's objectives.

Many researches have been carried out to solve distribution network reconfiguration problems using different methods for the last two decades. Merlin and Back [1] were the first to report a method for distribution network reconfiguration to minimize feeder loss. They formulated the problem as a mixed integer nonlinear optimization problem and solved it through a discrete branch-and-bound technique. Civanlar et al. [2] proposed a switch exchange method from which a simple formula for the estimation of the loss reduction by a particular switching option is developed. In [3], a binary group search optimization (BGSO) has been presented to handle the reconfiguration problem with power losses indices as an objective function. Duan et al. [4] have solved the reconfiguration problem for both the indices of power loss reduction and reliability improvement by using an enhanced genetic algorithm (EGA). In this work, GA has been improved on crossover and mutation operations to determine the switch operation schemes. In [5,6], a fireworks Algorithm (FWA) has been employed to minimize power loss and improve voltage profile and to optimize the distribution network configuration considering distributed generation. In [7], a method based on a shuffled frog leaping algorithm (SFLA) has been proposed to minimize the cost of power loss and power of distributed generators. A discrete artificial bee colony (DABC) has presented in [8] to optimize the distribution network. In [9], a method based on harmonic search algorithm (HSA) was developed for DNR problem to minimize power loss. In [10], a particle swarm optimization (PSO) was applied successfully to handle the reconfiguration problem with multi-objective functions. In [11], a new method was proposed for minimization of real power loss reconfiguration using adapted ant colony optimization. Sedighizadeh et al. [12] have proposed Hybrid Big Bang-Big Crunch algorithm (HBB-BC) to optimize the distribution network with objective functions of power losses, voltage stability, DG cost and greenhouse gas emissions.

Algorithms proposed for network reconfiguration problem, generally, can be classified into two following main classes: (1)

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Nomenclature

ΔP^R_{loss}	total power loss of the system after reconfiguration
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ΔP^0_{loss}	total power loss of the system before reconfiguration
N_{br}	total number of branches
N_{bus}	total number of buses
N_{ss}	the number of substations
P_i	real power load at bus i
Q_i	reactive power load at bus i
V_i	voltage magnitude at bus i
V_{min}	minimum acceptable bus voltage
V_{max}	maximum acceptable bus voltage
I_i	current at branch i
$I_{max,i}$	upper limit of line current as defined by the manufacturer

heuristic algorithms [1,2], such as discrete branch-and-bound technique and switch exchange algorithm and (2) intelligent algorithms [3–12], such as BGSO, EGA, FWA, SFLA, DABC, HSA and PSO. Among these algorithms, heuristic algorithms are all greedy search algorithm. They are easy to be implemented and with high searching efficiency, but generally cannot converge to the global optimum solution in the large-scale distribution systems. Intelligent algorithms can direct searching process to the global optimum at the probability of one hundred percent in theory. But they all inevitably involve a large number of computation requirements and really have a lot of control parameters.

The cuckoo search algorithm developed by Yang and Deb is a new meta-heuristic algorithm for solving optimization problems inspired from the obligate brood parasitism of some cuckoo species which lay their eggs in the nests of other host birds of other species. This is a more efficient algorithm compared with GA and PSO [13]. Marichelvam [14] proposed an improved hybrid cuckoo search algorithm for solving the permutation flow shop scheduling problems. In [15], a hybrid cuckoo search algorithm integrated with fuzzy system was proposed for solving multi-objective unit commitment problem. CSA was also implemented to solve the structural optimization tasks [16]. In this work, CSA has been tested on many design problems and obtained better solution than several methods in the literature such as adaptive response surface method (ARSM), improved ARSM and PSO. Recently, CSA has been further improved to minimize the completion time of the last job to leave the production system for the hybrid flow shop (HFS) scheduling problems [17]. In addition, CSA has been also proposed to track Maximum Power Point in the Photovoltaic (PV) system [18]. In this work, the tests have carried out for PV system when irradiance and temperature change gradually and rapidly. The tested results have been demonstrated that CSA outperforms both Perturbed and Observed (P&O) and PSO. Yang and Deb [19] have analyzed the CSA and found out why CSA is efficient. Recently studies have demonstrated that CSA is an efficient method for solving optimal problems.

In this paper, the CSA is proposed for solving distribution network reconfiguration problem considering power losses in transmission systems and voltage profile improvement. The effectiveness of the proposed CSA has been tested on different distribution network systems and the obtained results have been compared to those from other methods available in the literature such as existing FWA in [5,6], GA, ITS, RGA and HSA in [9,20] and a novel improved adaptive imperialist competitive algorithm (IAICA) in [21].

Problem formulation

Objective functions

The reconfiguration is defined as the process of changing the topology of system for a certain objective. The DNR is accomplished by changing open/close state of switches. In this study, the objective is to minimize total system active power loss and voltage deviation. The objective function can be described as follows [5]:

$$minimize\ F = \Delta P^R_{loss} + V_D \tag{1}$$

The net power loss reduced (ΔP^R_{loss}) is taken as the ratio of total power loss before and after the reconfiguration of the system:

$$\Delta P^R_{loss} = \frac{P^{rec.}_{loss}}{P^0_{loss}} \tag{2}$$

The total power loss of the system is determined by the summation of losses in all line sections:

$$P_{loss} = \sum_{i=1}^{Nbr} R_i \times \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) \tag{3}$$

The voltage deviation index (ΔV_D) can be defined as follows:

$$\Delta V_D = \max\left(\frac{V_1 - V_i}{V_1}\right) \forall i = 1, 2, \ldots, N_{bus} \tag{4}$$

The reconfigured process will try to minimize the ΔV_D closer to zero and thereby improves voltage stability and network performance.

Constraints

During network reconfiguration, the power flow analysis should be derived. For each proposed configuration, the power flow analysis should be carried out to compute the nodal voltage, power loss of system and current of each branch. The constraints of objective function are as follows:

(1) For the proposed configuration, the computed voltages and currents should be in their premising range.

$$V_{min} \le V_i \le V_{max}; \quad i = 1, 2, \ldots, N_{bus} \tag{5}$$

$$0 \le I_i \le I_{max,i}; \quad i = 1, 2, \ldots, N_{br} \tag{6}$$

(2) The radial nature of distribution network must be maintained and all loads must be served.

Checking radial topology

In this section a new algorithm is proposed for checking the radial topology of trial solutions. The flow chart of the algorithm is shown in Fig. 1.

Step 1: Initialize a connected matrix of the loop distribution network $A(b,b)$ with b is the number of buses of the network system. Each entry in matrix A is defined as follows:

$A(i,j) = 1$ and $A(j,i) = 1$ if node i is connected to node j.
$A(i,j) = 0$ and $A(j,i) = 0$ if node i is not connected to node j.