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A novel method based on adaptive cuckoo search for optimal network reconfiguration and distributed generation allocation in distribution network

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ABSTRACT

This paper proposes a new methodology to optimize network topology and placement of distributed generation (DG) in distribution network with an objective of reduction real power loss and voltage stability enhancement. A meta-heuristic cuckoo search algorithm (CSA) inspired from the obligate brood parasitism of some cuckoo species which lay their eggs in the nests of other birds of other species for solving optimization problems is adapted to simultaneously reconfigure and identify the optimal location and size of DG units in a distribution network. The graph theory is used to determine the search space which reduces infeasible network configurations of reconfiguration process and check the radial constraint of each configuration of distribution network. The effectiveness of the proposed method has been validated on three different distribution network systems at seven different scenarios. The obtained results show well the effectiveness and performance of the proposed method in distribution network reconfiguration with optimal location and size of DG problems.

Introduction

A distribution network is the last stage in delivery of electric power. It carries electricity from the transmission system to consumers. Distribution systems usually have high system losses and poor voltage regulation because of the high current and low voltage level in distribution systems [1,2]. In addition, due to the rapid expansion of distribution networks, the voltage stability of distribution systems has become an important issue. Therefore, many efforts have been made to decrease the losses and improve the voltage stability in distribution systems. Network reconfiguration and distributed generator placement are among those efforts to mitigate this problem [3].

Distribution network reconfiguration (DNR) is the process of varying the topology of distribution network by changing the closed/open status of sectionalizing and tie switches while respecting system constraints upon satisfying the operator's objectives [4]. The first publication about the DNR problem was presented by Merlin and Back [5]. They solved DNR problem through a discrete branch-and-bound type heuristic technique. Civanlar et al. [6] proposed a switch exchange method to estimate the loss reduction based on particular switching option. Since the method is based on heuristics technique, it is difficult to take a systematic way to evaluate an optimal solution. In recent years, new meta-heuristic methods have been proposed for solving optimization problems to obtain an optimal solution of global minimum in the literature with good results. In [7], a method based on an enhanced genetic algorithm was developed for DNR problem to minimize the power loss and maximize the system reliability. Souza et al. [8] proposed two new approaches for solving the DNR problem using the Opt-aiNet (artificial immune network for optimization) and Copt-aiNet (artificial immune network for combinatorial optimization) algorithms to minimize power loss. In [9], the network reconfiguration and capacitor placement are simultaneously employed to enhance the system efficiency in a fuzzy multi-objective optimization problem by using a binary gravitational search algorithm (BGSA).

Distributed generations (DGs), which are connected to the grid at distributed level voltages are generating plant serving a customer on-site. Because of the reasons of energy security and economical benefit, the presence of DGs into distribution networks has been increasing rapidly [10,11]. Impact of DG units on power

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Nomenclature

P_{loss}^{rec}	total power loss of the system after reconfiguration
P_{loss}^{0}	total power loss of the system before reconfiguration
N_{br}	total number of branches
N_{bus}	total number of buses
N_{DG}	number of distributed generators
P_i	real power load at bus i
Q_i	reactive power load at bus i
V_i	voltage magnitude at bus i
$P_{Dgmax,i}$	maximum size of distributed generator ith
V_{min}	minimum acceptable bus voltage
V_{max}	maximum acceptable bus voltage
I_i	current at branch ith
$I_{max,i}$	upper limit of line current as defined by the manufacturer
R_k	resistance of the line section between buses k and $k+1$
X_k	reactance of the line section between buses k and $k+1$

system has attracted the interest of some recent research efforts. In [12], authors proposed comparison of novel power loss sensitivity (NPLS), power stability index (PSI), and voltage stability index (VSI) methods for optimal allocation and size of DG in radial distribution network. In [13], a method based on bacterial foraging optimization algorithm (BFOA) is proposed to find the optimal location and size of DG with an objective of power losses reduction, operational costs and improving voltage stability. In [14], authors proposed a method based on the artificial neural network to find optimal DG size and locations due to complexity of multiple DG concepts. Kayal and Chanda [15] proposed a new constrained multi-objective particle swarm optimization (PSO) based wind turbine generation unit and photovoltaic array placement approach to reduce power loss and improve voltage stability of radial distribution system. In [16], a novel application of multi-objective particle swarm optimization was developed for determining the place and size of DGs, and the contract price of their generated power.

Recently, some researches have integrated both the DNR and DG placement problems to improve the effectively of distribution network [17–19]. In [18], the DNR problem in the presence of DG with an objective of minimizing real power loss and enhancing voltage profile in distribution network is solved based on the harmony search algorithm (HSA). In [19], a method based on fireworks optimization algorithm (FWA) is proposed for solving DNR together with DG placement to minimize power loss and improve voltage stability. Both researches [18,19] had used the different techniques to pre-identify the candidate bus locations for DG installation such as loss sensitivity factor (LSF) [18], and voltage stability index (VSI) [19].

Due to pre-identifying of location of DGs based on LSF or VSI in initial network configuration, the above methods focused only on sizing of DG units. However, these parameters may change during network reconfiguration process and DGs installation. In addition, in distribution systems with multi-DG units, these parameters may change more noticeable because of the interaction between DGs. In this paper, a method based on cuckoo search algorithm (CSA) [20] which is a recent meta-heuristic is proposed for solving the DNR problem in the presence of distributed generation. Compared to other algorithms, CSA has fewer control parameters and is more effective [4]. Recently, CSA has been applied to solve many power system problems and other fields such as optimal power flow (OPF) [21], power system stabilizers (PSSs) [22], load frequency control (LFC) [23], and automatic generation control (AGC) [24]. The results obtained from the above problems have proven the effectiveness of CSA compared to other optimization algorithms.

In this study, the proposed method based on CSA uses power loss and VSI index as objective functions to find the optimum configuration of distribution network, and the optimum bus location and size of DGs. The algorithm is tested on 33-bus, 69-bus and 119-bus systems and results obtained are compared with other techniques available in the literature.

Problem formulation

Objective functions

One of the main advantages of the optimal network reconfiguration and DG installation is the reduction in power loss. The net power loss reduced (ΔP_{loss}^{R}) is taken as the ratio of total power loss before and after the reconfiguration considering DGs of the system:

$$\Delta P_{loss}^{R} = \frac{P_{loss}^{rec.}}{P_{loss}^{0}} \tag{1}$$

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

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

On the other hand, as DGs are installed in distribution network, the bus voltages will increase and voltage security will enhance. Therefore, to obtain maximum benefit from the DG, suitable location and sizing have to be determined before its installation based on voltage stability index (VSI). VSI is a parameter that identifies the near collapse nodes. The node with small VSI is more sensitive to voltage collapse. According to Fig. 1, VSI of node 2th to node Nth is calculated as follows [25,16]:

$$\begin{aligned} \text{VSI}_{(k+1)} = {} & |V_k|^4 - 4(P_{k+1}X_k - Q_{k+1}R_k)^2 \\ & - 4(P_{k+1}R_k - Q_{k+1}X_k)|V_k|^2 \end{aligned} \tag{3}$$

where P_{i+1}, Q_{i+1} are total real power and reactive power load fed through node $(k+1)$, respectively.

If the VSI for each bus is higher, the stability of that relevant node shall be better. In distribution network reconfiguration considering DGs, the voltage stability deviation index (ΔVSI) can be defined as follows:

$$\Delta \text{VSI} = \max\left(\frac{1 - \text{VSI}_i}{1}\right) \quad \forall i = 2, \ldots N_{bus} \tag{4}$$

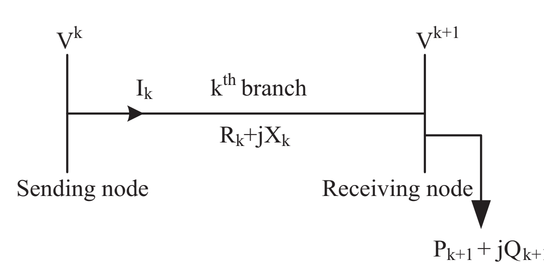

Fig. 1. A branch of a radial distribution system.