Electrical Power and Energy Systems 64 (2015) 88–95

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Reconfiguration of distribution network for loss reduction and reliability improvement based on an enhanced genetic algorithm

Dong-Li Duan [a,*], Xiao-Dong Ling [b], Xiao-Yue Wu [c], Bin Zhong [a]

[a] College of Equipment Engineering, Engineering University of Armed Police Force, Xi'an 710086, China
[b] China Satellite Maritime Tracking and Control Department, Jiangyin 214431, China
[c] College of Information Systems and Management, National University of Defense Technology, Changsha 410073, China

ARTICLE INFO

Article history:
Received 3 July 2013
Received in revised form 17 June 2014
Accepted 6 July 2014

Keywords:
Distribution system reconfiguration
Reliability evaluation
Power loss
Genetic algorithm

ABSTRACT

Electrical distribution network reconfiguration is a complex combinatorial optimization process aimed at finding a radial operating structure that minimizes the system power loss or/and maximizes the system reliability while satisfying operating constraints. In this paper, a distribution network reconfiguration method is presented for both the indices of power loss reduction and reliability improvement. The enhanced genetic optimization algorithm is used to handle the reconfiguration problem so as to determine the switch operation schemes. Based on the information of a single loop caused by closing a normally open switch, we improve the algorithm on crossover and mutation operations of original Genetic Algorithms. The effectiveness of the proposed method is demonstrated on 33-bus, 69-bus, and 136-bus radial distribution systems.

Introduction

Motivation

As one of the most important content in distribution automation research, network reconfiguration of distribution feeders is performed to improve system operating conditions and reduce system cost. It is a process that alters feeder topological structure, changing the open/close status of sectionalizing switches and tie switches in system. Majority of works reported in the existing literatures aim at minimizing real power loss in distribution network or balancing load distribution. It has, however, been reported in the technical literature that approximately 80% of the customer interruptions occur due to the problems in distribution networks [1,2]. Therefore, reliability is also an essential criterion for reconfiguration problem.

Traditionally, network reconfiguration for loss reduction problem is formulated as a multiobjective problem when considering other parameters related to the system reliability [3]. Due to the nonlinear characteristics of electrical behavior constraints and large number of switching elements in distribution networks, reconfiguration problem generally is a highly complex combinatorial and constrained nonlinear mixed integer optimization problem. To find an appropriate solution for this kind of problem, meta-heuristic methods are frequently used [4–8].

One of these methods, the genetic algorithm (GA), is highlighted in this paper. One of the most principal difficulties is the radiality constraint in GA operators (mutation, selection, and crossover), which ensures that the network topology operation should be radial. Nevertheless, this paper presents an approach based on an enhanced genetic algorithm (EGA). It properly deals with the radiality constraint to generate feasible solution in GA operators. Therefore, it explores the search space more efficiently, producing better solutions for distribution reconfiguration problem.

This paper deals with the above mentioned proposals to find efficient solutions. The main contribution is the new algorithm that, always, generates radial topologies after the implementation of the genetic operators. This proposal is incorporated in a specialized genetic algorithm allowing the appropriated control of the diversity. However, the proposal of this genetic algorithm is only a collateral contribution. The algorithm presented is set up to solve the reconfiguration problem, and it can also be generalized to solve other problems of the same family, such as multiobjective reconfiguration and reconfiguration with variable demands.

Prior work

It is satisfied with the application of GA to solve the optimization problem with discrete random variables and nonlinear

* Corresponding author. Tel.: +86 15691716811.
E-mail address: mineduan@163.com (D.-L. Duan).

http://dx.doi.org/10.1016/j.ijepes.2014.07.036
0142-0615/

objective functions. It has been clearly demonstrated to be both feasible and advantageous, as GA or the enhanced GA approach can efficiently identify the optimal or near optimal network configurations [9,10]. Moreover, it has been found using GA to resolve the planning problem of large-scale power distribution networks is more suitable and efficient than several other methods [11,12]. In spite of that, its main drawback is the slow convergent velocity and the required running time.

In order to acquire better solutions and mitigate the computational burden, considerable efforts have been made to solve the problem. Researchers mainly set about from two aspects: topology coding strategies and genetic operator(crossover and mutation) modifying method.

For GA, the topology coding strategies must permit the genetic operators to be performed in an efficient way. Practically, all the evolutionary algorithms use a codification vector which, after being decoded, represents a radial distribution network topology. The binary coding strategy is the most simple but the least effective in terms of space memory or GA operators success. It takes a string formed by the binary status (closed/open) of each network switch [13,14] as the distribution configuration. The arc number(binary string) and the switch position in each open branch are considered for the feasible radial system in [11]. The topology string is simplified by only the opened switch number in [15]. Based on the concept of path(a set of branches from node to the source), the topology string is composed of all the paths in [16], where the state of each path is represented by a binary variable. It should be noted that only a path to the source for each node is considered for a radial configuration. An encoding scheme with real numbers is adopted in [17–19] based on the concept of fundamental loops or the cut set of each loop. A Prufer number encoding/decoding scheme based on the spanning tree concept is given in [20], which can avoid the tedious "mesh check" algorithm. Actually, a complex strategy could reduce considerably the convergence time on the one hand. On the other hand, a simple strategy would decrease the exploration effectiveness in the research field [19].

A great majority of the GA applications to the reconfiguration problem use the traditional crossover and mutation techniques [11,21,22,20], in which the crossover operator always do not generate a new radial topology. New radial topologies can be always generated by the mutation operator. Therefore, the proposals in [23–25] are implemented using only the mutation operator and avoiding using the crossover operator. A process is developed to change the crossover and mutation probability in [14,15]. In [26], an accentuated crossover process is presented, in which the information of the fundamental loops is used to form a codification vector whose size is equal to the number of branches out of the tree. This information, along with the information of the loops, allows the recombination operator to be implemented in an adequate way. This type of operator is efficient, but the radiality of the generated topologies must be checked. In [20], the combination of two prufer numbers generates another prufer number, that after being decoded, represents another radial topology. Some radial topologies generated could be unfeasible, because there are radial topologies for the interconnected graph, but not for the electrical system. In [19], a theoretical approach based on the graph and matroid theories (graphic matroid in particular) is proposed to deal with the crossover and mutation operator, it also needs the information of fundamental loops. When applied to complex distribution networks, the loop identification could be much more difficult. By far, there is no efficient algorithms to list automatically the fundamental loops for a given graph. Therefore, we need explore more efficient algorithm to solve the problem avoiding to find fundamental loops and perform mesh check.

There is also previous related work that considers multiobjective versions of the reconfiguration problem. For example, five objectives are combined into one equation using weighting factors in [27]. Several objectives are modeled with fuzzy sets in [28] so that they are evaluated in a single equation as well. The objectives considered include power losses, voltage drop, margin of transformer, balance service of important customers, switching operation, branch current loading and feeder load balancing. In [29], the original non-dominated sorting genetic algorithm (NSGA) is employed as the search engine to find the trade-off region between the construction cost of the network and the non-supplied energy. With the enhanced technique non-dominated sorting genetic algorithm-II (NSGA-II), the cost of the network and the cost associated to the occurrence of faults are considered as the objective functions in [30]. In [31], a microgenetic algorithm (uGA) is presented to handle the reconfiguration problem with power losses and reliability indices as two objective functions.

This paper, therefore, proposes an enhanced GA for automated reconfiguration of an existing distribution network to determine the optimal topology which yields the minimum power loss or/and the maximum system reliability. The coding strategy uses the open switch number representation. An approach based on the information of a single loop caused by closing a normally open switch is to perform the GA operators.

Paper organization

This paper is organized as follows: Section "Problem formulation" gives a mathematical model for the distribution network reconfiguration problem. A description of the EGA algorithm is presented in Section "Reconfiguration method". Simulation results of test cases are presented in Sections "Case studies" discusses and concludes this paper.

Problem formulation

Power loss of radial distribution network

The power flows are calculated by the following set of recursive equations derived from the single-line diagram in Fig. 1 [32,33].

From Fig. 1, the voltage phasers at buses i and $i+1$ are $V_i\angle\delta_i$ and $V_{i+1}\angle\delta_{i+1}$, respectively. The current $\widetilde{I}_{i+1}$ from bus i to bus $i+1$ (neglecting the shunt flow) is given by

$$\widetilde{I}_{i+1} = \frac{V_i\angle\delta_i - V_{i+1}\angle\delta_{i+1}}{R_{i+1} + jX_{i+1}} \tag{1}$$

Here, R_{i+1} and X_{i+1} are the resistance and reactance of the branch from bus i to bus $i+1$. The load power consumption is given by

$$P_{i+1} - jQ_{i+1} = \widetilde{V}_{i+1} * \widetilde{I}_{i+1} \tag{2}$$

From (1) and (2), the voltage magnitude of V_{i+1} at node $i+1$ is given by

$$V_{i+1} = \left\{ \left[\left(P_{i+1}R_{i+1} + Q_{i+1}X_{i+1} - \frac{|V_i|^2}{2} \right)^2 - \left(R_{i+1}^2 + X_{i+1}^2\right)\left(P_{i+1}^2 + Q_{i+1}^2\right) \right]^{1/2} - \left(P_{i+1}R_{i+1} + Q_{i+1}X_{i+1} - \frac{|V_i|^2}{2} \right) \right\}^{1/2} \tag{3}$$

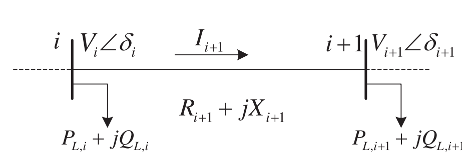

Fig. 1. single-line diagram for power flow calculation.