Electrical Power and Energy Systems 41 (2012) 71–75

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

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

An efficient heuristic algorithm for reconfiguration based on branch power flows direction

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ARTICLE INFO

Article history:
Received 31 May 2011
Received in revised form 16 November 2011
Accepted 10 March 2012
Available online 21 April 2012

Keywords:
Reconfiguration
Heuristic
Distribution systems
Breakpoint node
Loss minimization

ABSTRACT

This paper presents a meshed algorithm for optimal reconfiguration of distribution systems. In the reconfiguration problem, the final objective is to reach a radial network that optimizes some function like the network losses. Many algorithms start from a radial network where a switch closure is complemented by opening of another switch to ensure a radial network. These radial algorithms have an inherent inconvenient, that is, the final solution depends on the initial radial network selected. Other group of algorithms initially represent the distribution network as a meshed network and then open switches until a radial system is obtained. In this paper, to avoid the above aforementioned inconvenient of radial algorithms, a meshed algorithm is used. Furthermore, taking into account that breakpoint nodes are defined as the nodes where the branch power flows converge, the contribution of this paper is to provide a method for solving the problem when multiple loops are considered using an approach based on the breakpoint nodes, since it is complicated to associate each breakpoint node with its corresponding loop. On the other hand, one of the drawbacks of the reconfiguration problem is the need to solve a great number of power flow computations for calculating the losses in each stage of the algorithm. The algorithm proposed has the property that reduces the number of power flows. By this way, the execution time of the algorithm is improved. Besides, it is not necessary to check the network connectivity at each step of the procedure. To prove the effectiveness of the proposed algorithm several test systems have been used, achieving good results.

1. Introduction

Losses in electric power systems are an inherent consequence of energy transmission from generation to consumers. The electric power systems consist of three subsystems: generation, transmission and distribution, being the last one the most numerous. Besides, due to the low voltage level, losses are greater in distribution systems than in transmission systems. This is why reducing losses in distribution systems remains an interesting line of research.

In general, distribution systems are structurally meshed, but technical considerations make that they are radially operated. To achieve the final radial network switches are installed for changing the network topology. This process is denominated as the reconfiguration problem, which is widely studied. Nevertheless, new techniques are continuously appearing in order to achieve a global optimal solution and to reduce the computation time.

There are many approaches to solve the reconfiguration problem. A first collection of the different techniques was published by Sarfi et al. [1], where a review and a classification of different techniques was presented, that is: blending heuristic and optimization, algorithms based solely on heuristic and artificial intelligent techniques.

Regardless of the technique used, and considering the structure of the algorithm, these ones can be divided into two main groups, namely, algorithms that start from a network with all switches closed and algorithms that start from a radial network.

Meshed algorithms are characterized by opening a branch in each step of the algorithm to achieve a radial network. What differentiates each meshed algorithm is the method or criterion used to decide the branch to open in each step of the algorithm. Moreover, radial algorithms start from a radial network with a number of branches initially opened. At each step of the algorithm, a branch is closed, so a mesh is created. Thereupon, similarly to meshed algorithms, different approaches are used to decide which branch is selected to open. This process is repeated until an acceptable solution is achieved.

Merlin and Back [2] were the first to raise the issue of reconfiguration, using a meshed algorithm where a minimal-loss load flow was used to decide the branch to be opened. In contrast to Merlin

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http://dx.doi.org/10.1016/j.ijepes.2012.03.009

and Back, Civanlar et al. [3] were the first using a radial algorithm where a simple formula was used to evaluate the losses increase.

Other papers using the same structures but with different approaches are continuously appearing. Among others, Refs. [4–7] make use of meshed algorithms and Refs. [8–10] of radial algorithms.

In Ref. [4], Viswanadha and Bijwe made use of real power loss sensitivity with respect to the impedances of the candidate branches to select the branch to be opened. Another meshed algorithm was used by Singh et al. in [5], where proposed opening of a branch in a loop carrying minimum resistive power flow. de Oliveira et al. [6] made use of a mixed integer non-linear programming approach, in which a continuous function is used to handle the discrete variables and Chandramohan et al. [7] use a non-dominated sorting genetic algorithm (NSGA) for reconfiguring to minimize its operating costs considering the system real power transmission loss and the cost of reactive power purchased by the distribution system.

With respect to deal with the problem of reconfiguration through radial algorithms, in Ref. [8], Zhang et al. proposed a joint optimization algorithm of combining network reconfiguration and capacitor control. Bernardon et al. [9] proposed a new fuzzy multicriteria decision making algorithm for the proper processing of the information sources available at the utilities in the context of distribution network reconfiguration. And recently, Ababei and Kavasseri [10] have proposed an efficient heuristic algorithm to solve the distribution network reconfiguration problem for loss reduction.

Apart from these two large groups, a third group is formed by the union of a meshed and a radial algorithm, that is, a meshed algorithm is executed to give an initial solution for the radial algorithm. The paper proposed by Gomes et al. [11] belongs to this latter type. Finally, there are other algorithms that do not belong to the aforementioned groups like the heuristic constructive algorithm proposed in [12] by McDermott et al.

Finally, Zhang et al. [13], have proposed a reliability-oriented reconfiguration (ROR) method that deals with uncertainties in loads, generations, electrical and economic parameters and ambiguous reliability parameters for distribution network reconfiguration.

This work is an improvement of that published in [14] where a radial algorithm based on branch power flow directions was used. However, that approach did not consider the possibility that the algorithm started from a meshed network, where multiple loops were taken into account. The contribution of this paper is to provide a method for solving the problem when multiple loops are considered using the proposed approach. Overall, radial algorithms have the inconvenient that the final solution depends on the initial radial network selected. So, to avoid the above aforementioned inconvenient of radial algorithms, a meshed heuristic algorithm for optimal reconfiguration of distribution systems is now presented in this paper based on the direction of branch active and reactive power flows. Taking into account the above, a set of candidate branches to be opened are selected in each step of the algorithm in order to reach the radial network.

To conclude, the paper is organized as follows: Section 2 covers the proposed heuristic technique and the study of the candidate branches to be selected. In Section 3, the algorithm is described. Test systems and numerical results are explained in Section 4 and finally, in Section 5 the final conclusions are presented.

2. Heuristic technique

An extended description of the heuristic is described in Ref. [14] when only one loop is considered. That heuristic is based on the direction of power flows through the branches of the network.

Since the complex power in alternating current networks has no direction, active and reactive powers are used instead of complex power, and thus, two different power flows are represented separately in the network. In this way, two directed graphs are obtained.

Once the network is represented by two directed graphs, particular nodes (buses) in each graph have the characteristic that the flows entering in the node are more or equal than two. These characteristic nodes are called active breakpoint node (P-breakpoint) and reactive breakpoint node (Q-breakpoint), and the branches entering in the breakpoint nodes are chosen as candidates to be opened. Thus, the number of candidate branches to be opened is generally reduced to two, instead of all the branches forming the loop.

When the network has only one loop, the set of the candidate branches depends on the situation of the breakpoints in the loop. Two different cases can appear in a single loop if capacitor banks are not considered: P-breakpoint and Q-breakpoint are the same node and P-breakpoint and Q-breakpoint are different nodes. The candidate branches in these two cases are respectively: only the two branches entering in the breakpoint node and the collection of the branches entering in the P and Q nodes plus the branches of the path between the two nodes.

The cases commented in paragraph above are valid for a single loop. Considering a network with l loops, in general, there will be so many breakpoint nodes as loops. This is true when all breakpoint nodes have in degree equal to two (the number of power flows entering in the node is two). It could happen that the number of power flows entering in a node was more than two, for example, three. In this case, the number of breakpoint nodes decreases in a unit. Therefore, if the in degree of a node is two, the number of candidate branches is two, if it is three, the set of candidate branches is three taking two by two, and so on.

For a network with n nodes and b branches, the relation between the number of P-breakpoint or Q-breakpoint nodes (n_{BN}) and their respective in degree is expressed by:

$$n_{BN} = b - (n - 1) - \sum (g(i) - 2), \quad \forall i \in BN/g(i) > 2 \tag{1}$$

where BN is the set of breakpoint nodes; $g(i)$ in degree of the breakpoint; b the number of branches; and n is the number of nodes.

On the other hand, the number of candidate branches for each breakpoint node will be equal to the in degree of the node.

Generally, the active and reactive breakpoint nodes in a mesh network do not have to coincide and moreover, the in degree of the breakpoint nodes could be greater than two. This is an inconvenient because the goal is to get so many breakpoint nodes as loops has the network. So, it is necessary to pair off each P-breakpoint to its corresponding Q-breakpoint. To solve this drawback, an adequate set of rules have been developed.

These rules are:

- There will be as many pairings as loops in the network.
- The number of times that a breakpoint node will be paired off will be equal to its in degree less one.
- When P-breakpoint and Q-breakpoint were the same node, they will be paired off. These nodes will be paired off as many times as they coincide according to their in degrees.
- For the rest of breakpoint nodes, a path is looked for trough the branches that have opposite active and reactive power flow directions starting at a P-breakpoint node until a Q-breakpoint node is reached.

To illustrate how the pairings are done, a hypothetical network has been considered.