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Fast solution of radial distribution networks with automated compensation and reconfiguration

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Abstract

Optimal operation of radial distribution networks with automated compensation and reconfiguration requires the solution of a combinatorial optimisation problem, since the variables are the on/off status of capacitor banks and the open/close status of tie-switches. The solution approaches recently proposed use iterative algorithms such as genetic algorithms, simulated annealing and tabu search, for which the network needs to be solved in different configurations and at different compensation levels. The aim of this evaluation is that of attributing a quality index to each solution so that all the solutions can be suitably ordered. In an automated network, any configuration can be obtained from another one through a set of elementary moves, each consisting of the change of status of a pair of tie-switches. In the same way, any compensation level can be obtained from another one through a set of elementary moves, each consisting of the change of status of a capacitor bank. Once the most important quantities of the network in the starting configuration are calculated, those in the final configuration can be determined assessing the variations due to the series of elementary operations performed on the network that are necessary to go from the starting configuration to the final one. In the present paper, the expressions for the calculation of power losses and bus voltage variations in a radial network due to an elementary reconfiguration move or an elementary compensation move are developed. These expressions are obtained on the basis of the hypotheses usually valid for distribution networks. They can be easily integrated in any algorithm for optimal reconfiguration and compensation, making easier its implementation and faster the solution attainment. Simplified feeder models for distribution feeders with many loads, have also been developed in order to further reduce computation time. Substitution of all feeders with an equivalent one having only one ending load, together with performing evaluations only for a reduced number of network branches, gives rise to remarkable savings, in terms of computation efforts, growing with the network size and the number of loads.

Keywords: Radial distribution network; Automated compensation; Reconfiguration

1. Introduction

In the field of distribution automation, optimal reconfiguration and reactive power compensation allow the attainment of some important goals such as, reduction or power losses; voltage profile flattening; load balancing between HV/MV transformers and service restoration.

During normal system operation, the optimisation of reconfiguration and compensation requires the solution of a combinatorial optimisation problem. As usual MV systems sizes do not allow any enumerative approach, heuristic approaches have been applied and they have proved to work out well for this kind of problem. Even though they do not guarantee optimality of final solutions, they lead to sub-optimal solutions that are technically acceptable. The most commonly used methodologies are those based on genetic algorithms, simulated annealing, tabu search and evolutionary computation [1–3]. Two fundamental steps of such techniques are, the attribution of a quality index to each solution and the perturbation mechanism. The quality index, of course, depends on the objectives to be attained such as power losses, voltage profile and load balancing. The search mechanism proceeds through iterated perturbations on the network configuration

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and/or the compensation system status and the consequent network solution. Therefore, the network must be solved a high number of times; obviously, the calculation time to get the final solution strongly depends on the time needed to solve the network.

The problems of the memory commitment reduction and of the calculation time reduction have been widely dealt with in literature. For radial distribution networks, some authors have proposed the reduction of the actual network having long feeders with many loads, in a network made up of the same number of feeders but each of them with a single equivalent load. In this view, the problem is shifted to the identification of an equivalent feeder structure, for which it is easy to make the required evaluations. In [4–6] equivalent models for feeders are proposed. The model presented in [4] is developed for feeders that can be supplied at one end. The one developed in [5], even if bi-directional, does not give any computational benefit, when applied to optimisation strategies for automated distribution networks, where it is required to repeatedly perform the networks state evaluation, as the compensation level and the loads entity vary. At each of these changes, the models developed in [5] require the entire calculation of the equivalent model parameters. This problem has been overcome in [6]. Here, a bi-directional feeder model is proposed allowing complex network changes taking place when the reconfiguration operations are carried out; moreover, the equivalent feeder models are defined depending on the calculations to be executed for the network (voltage and power losses evaluations).

In the optimisation problem solution with heuristic and iterative procedures, it is important to point out that the solutions must be ordered on the basis of quality indexes, whose absolute value is not important. For this reason, if one solution is obtained from another one, for which the parameters on which the quality indexes depend are known, then the values of the variations of these parameters allow the assessment of the new quality indexes values.

For a radial network, any configuration can be derived from any other through a set of elementary moves, for each of which only the open/close status of a pair of tie-switches changes. In the same way, if the network is provided with switchable capacitor banks, any of the capacitor bank layouts can be derived from any other through a set of elementary moves, for each of which only the status of a single capacitor bank changes. The modification of the configuration through the status exchanges of a pair of tie-switches is here called a reconfiguration elementary move, while the change of status of one capacitor bank is here called a compensation elementary move.

In the present paper, the power losses and voltage variations expressions for reconfiguration or compensation elementary moves in a radial network have been developed on the basis of the hypotheses that are usually valid for distribution systems. The calculation times can be further improved, if any network feeder with many loads is modelled by an equivalent feeder with a single load at the ending bus. The relevant expressions are also presented.

2. Problem formulation

In automated networks, usually tie-switches and capacitor banks can be remotely controlled. Once a starting radial configuration and a certain compensation level are fixed (reference network), power losses and voltage levels can be assessed. As loads can be described by means of a constant current model, the network can be easily solved using the impedance matrix. This hypothesis is acceptable since the final objective is not that to exactly know the network status, but to compare, through a quality index on purpose implemented, one solution with another [7]. For the same network, a different radial configuration and a different compensation level (final configuration) can be considered as derived from the reference network through the following steps,

1. keeping unchanged the network configuration, the number of elementary compensation moves to be performed so as to bring the network in the final compensation status equals the number of capacitors that are in a different status, comparing the starting and the final configurations; the elementary variations due to each of these moves can be quantified in terms of power losses and of voltage variation;
2. keeping unchanged the final compensation status, all the reconfiguration elementary moves are performed so as to bring the network in the final configuration status and, at each elementary reconfiguration move, the relevant variations can be evaluated, so that the final voltage and power losses variations can be determined.

This is not the only possible path from the reference network to the final configuration. Elementary moves can be executed in any sequence, so that the path from the starting configuration to the final one is perfectly decomposable into elementary steps, that are reconfiguration and compensation moves.

In a radial network whose loads can be represented through a constant current model, the status change of a capacitor bank installed at one node determines the variation of the current flow only in the branches connecting the given node with the HV supply node of the whole network. Only in these branches, power losses variations can be appreciated. All the network nodes are subjected to voltage variations.