Scalable algorithm for the dynamic reconfiguration of the distribution network using the Lagrange relaxation approach

Neven V. Kovački, Predrag M. Vidović, Andrija T. Sarić

University of Novi Sad, Faculty of Technical Sciences, 6 Dositeja Obradovića Sq., Novi Sad, Serbia

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This paper proposes a new methodology for the dynamic reconfiguration of the distribution network (DRDN) which is based on the Lagrange relaxation approach. The aim of DRDN is to determine the optimal topologies (configurations) of the distribution network over the specified time interval. The objective is to minimize the active power losses, subject to the following constraints: branch power flow capacities, allowed ranges of bus voltages, radial network configuration, and limited number of switching (open/close) operations for all switching devices. The paper first introduces the “path-switch-to-switch” approach for the modelling of distribution networks, which is used to formulate DRDN as the mixed integer linear programming (MILP) problem. Then, the specified MILP problem is solved using the Lagrange relaxation approach in two-step procedure. In the first step, the associated Lagrange dual problem is solved, which is created by relaxing the switching operation constraints. The Lagrange dual problem is decoupled and much easier to solve than the original problem. In the second step, the solution of the Lagrange dual problem is used to perform the heuristic search, providing the suboptimal, though feasible solution of the original problem. Finally, the presented DRDN model is extended to multi-objective formulation, which also includes the impact of the network reliability and the switching costs to the DRDN process. The robustness and scalability of the developed algorithm (for application in large-scale distribution networks) are demonstrated with two test examples: 15-bus test benchmark and 1021-bus real-world test system.

1. Introduction

1.1. Motivation and aim

The reconfiguration of distribution networks is an optimization procedure which determines the optimal network configuration by changing the status (open/close) of switching devices. It is widely used in distribution networks for active power losses reduction, relief of overloads (load balancing), Volt/Var support (maximizing the loadability), supply restoration, and others [1]. In many studies, the network reconfiguration is treated as the static problem, where the optimal network configuration is determined for a fixed operation point (load/generation condition). However, this approach is not suitable for real-time applications, due to the time-varying nature of distribution networks: variable loads, increased penetration of renewable resources, storage systems, plug-in vehicles, and other stochastic elements. To enable efficient and secure distribution network operations in such environment, many researches define the network reconfiguration as a dynamic problem, where a set of network configurations is determined to optimize the network operations over the specified time period.

The DRDN is applicable to fully automated distribution networks only. In cases where the level of automation is limited to normal open- and mid-points, optimal reconfiguration is typically performed once a year. The recent trend towards the fully automated distribution networks creates opportunities for the application of intra-day reconfigurations in distribution networks to optimize daily network operation. However, the dynamic reconfiguration is quite limited with the number of switching operations, namely too frequent switching operations may have a negative impact on the distribution network, such as: reducing the expected life span of switching devices, increased risk of outages, stability problems during switching procedures and others. Therefore, the limits on the number of switching operations need to be considered in the dynamic reconfiguration problem.

Note that vectors and matrices are denoted in bold.
The early studies in this area were focused on minimizing the active power losses and load balancing among the distribution feeders [2–4]. To overcome the shortcoming of a fixed operation time interval, specialized methods have been developed, determining the optimal network configuration that minimizes the energy losses [5] and operation costs [6] over a specified time period. Optimization methods used for the static reconfiguration problem can be divided into deterministic optimization methods and heuristic methods. The first set of optimization methods includes mixed-integer programming [7–12] and Benders decomposition based algorithms [13]. The advantage of these methods is in their potential to solve the network reconfiguration problem with global optimality using standard solvers. There are also several heuristic methods, such as genetic algorithm [12,14], artificial neural networks [15], particle swarm optimization [16], simulated annealing.
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