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Graph theory based formulation of multi-period distribution expansion problems

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1. Introduction

Distribution expansion planning is a complex combinatorial optimization problem. Various heuristic and mathematical models proposed for solving such a complex problem have been categorized in several ways [1–5]. One of the major characteristics of these models is whether they consider a single planning period or multi-planning periods. Although multi-period problems are far more challenging to formulate and considerably more complex computationally, they produce more consistent and economic expansion plans. The multi-period problems are formulated as complete dynamic problems [1,6–9,11–16] and decomposition problems [4,17–23].

Complete dynamics refers to multi-period planning problems formulated within a single algorithm. Two main groups of methods have been used for solving such problems: artificial intelligence (AI) based methods [6–8] and mathematical programming based methods [1,11–16].

The proposed complete dynamic AI models are mostly based on genetic algorithms (GAs). They employ classical genetic operators (mutation and crossover) to model interactions between periods. The inadequacy and inefficiency of such conventionally structured GAs for solving distribution network planning problems have been noticed in [9,10].

ABSTRACT

In this paper a multi-period planning problem, with arbitrarily defined planning goals, is formulated in terms of graph theory. The proposed formulation represents a multi-period planning problem as a weighted graph problem and thus decomposes original problem into a number of sequences (spanning paths) of static planning problems without loss of accuracy. This graph problem is solved using dynamic programming technique. The proposed dynamic programming algorithm guaranties that optimal solution of multi-period planning problems will be found efficiently, assuming that optimality of static planning problems is guarantied. Detailed numerical results and comparisons presented in the paper show that proposed approach could improve noticeably the quality of multi-period solutions.

Mathematical programming based methods mostly employ mixed integer linear programming (MILP) algorithms [1,11–16]. The majority of proposed MILP models do not properly take into account load reallocation and upgrade possibilities in distribution networks, which can improve the quality of multi-period solutions [6,14]. Besides, because of significant computational complexity of MILP models, which additionally increases in multi-period problems due to interactions that exist between periods (subproblems) [24], they become limited to smaller size multi-period problems.

Decomposition models aim to reduce computational complexity of complete dynamic models and to enable handling of larger size problems by dividing multi-period problems into a number of single-period (static) planning problems. The most common decomposition approaches are based on forward fill-in concept [3,4] and backward pull-out concept [17–21]. The first one consists of solving the static expansion problems sequentially for all periods (starting from the first one) considering in the next period the enhancements implemented in the past. The second concept proposes that the set of enhancements, which meets the planning goals in the horizon period, is determined first. Then, static optimization is performed for each of the intermediate periods between the horizon period and the base, using only the elements determined in the first step. Decomposition algorithm presented in [22] employs heuristic forward/backward procedure to generate possible interactions between periods and heuristic rules to model each of them. In [23], these possible interactions are generated within the proposed iterative procedure and heuristic formulation is developed for their modeling. Heuristics used in all proposed decomposition algorithms take into consideration only a part of interactions that exist between periods. Furthermore, the considered interactions

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