An Approach Based on the Strength Pareto Evolutionary Algorithm 2 for Power Distribution System Planning

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Abstract. The vast majority of the developed planning methods for power distribution systems consider only one objective function to optimize. This function represents the economical costs of the systems. However, there are other planning aspects that should be considered but they can not be expressed in terms of costs; therefore, they need to be formulated as separate objective functions. This paper presents a new multi-objective planning method for power distribution systems. The method is based on the Strength Pareto Evolutionary Algorithm 2. The edge-set encoding technique and the constrain-domination concept were applied to handle the problem constraints. The method was tested on a real large-scale system with two objective functions: economical cost and energy non-supplied. From these results, it can be said that the proposed method is suitable to resolve the multi-objective problem of large-scale power distribution system expansion planning.

1 Introduction

A power distribution system is a network that consists of substations (electrical power source nodes), lines (electrical conductors connecting nodes and carrying power) and customers (power demand nodes). System planners must ensure that there is adequate substation capacity, line capacity and acceptable level of reliability to satisfy the power demand forecasts within the planning horizon. Planning these systems involves various tasks [1]; the main of these are: 1) To find the site of substations and lines, 2) To determine substations and lines sizes (substations and lines capacities) and 3) To determine the electrical power flow in substations and lines. These tasks have to be done simultaneously optimizing various objectives such as economical costs and reliability of the systems, and considering three main technical constraints: voltage drop limit, substation and line capacity limit and radial configuration (spanning tree configuration).

The vast majority of the developed planning methods consider only one objective function to optimize [2]. The objective function of these methods represents the economical costs of the system such as, investment, energy losses and interruption costs. However, there are other planning aspects that should be considered in the planning methods but they can not be expressed in terms of costs. For instances, environmental and social impact can be very important in some cases and they can not be expressed as economical costs. Reliability of the system is another planning aspect that have

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been expressed in terms of costs and considered in some planning methods but, it is required information about the economical impact of power interruptions on customers and suppliers. This information might be difficult to obtain in some cases. Therefore, some planning aspects to be considered need to be formulated as separate objective functions.

There are few multi-objective methods that have been proposed to resolve the problem of power distribution systems expansion planning with more than one objective function separately formulated. In [3], a planning method is proposed to optimize three objective functions: economical cost, energy non-supplied (a reliability index) and total length of overhead lines. This method generates a set of Pareto-optimal solutions using the ε-constrained technique. This technique transforms two objectives into constraints, by specifying bounds to them (ε), and the remaining objective, which can be chosen arbitrarily, is the objective function to optimize. In other words, the multi-objective problem is transformed into a single-objective optimization problem, which is resolved by classical single-objective algorithms. The bounds ε are the parameters that have to be varied in order to find multiple solutions.

Another planning method that uses the ε-constrained technique is reported in [4]. This method resolves the single-objective problems using a simulated annealing algorithm. The disadvantage of this technique is that the solution of the resulting single-objective problem largely depends on the chosen bounds ε. Some values of ε might cause that the single-objective problem has no feasible solution. Thus, no solution would be found. In addition, several optimization runs are required to obtain a set of Pareto-optimal solutions.

In [5], it is reported a planning method that uses the weighting technique to obtain non-dominated solutions. This technique consists in assigning weights to the different objective functions and combining them into a single-objective function. The Pareto-optimal solutions are identified by changing the weights parametrically with several optimization runs. One difficulty with this technique is that it is difficult to find a uniformly distributed set of Pareto-optimal solutions. In addition, many weight values can lead to the same solution and, in case of non-convex objective space, certain solutions can not be found.

In [6], a multi-objective optimization method based on genetic algorithms is presented. This method is able to find a set of approximate Pareto-optimal solutions in one single simulation run due to its population approach. The method is formulated to find the site and size of substations and lines optimizing two objective functions: economical cost and energy non-supplied. The drawback of this method is that the genetic algorithm has to be run several times in order to obtain solutions closer to the optimal ones. Moreover, the method uses genetic operators that generate many illegal solutions and its encoding technique has low heritability, making the algorithm inefficient and ineffective.

In this paper, we propose a new multi-objective planning method for optimal power distribution system expansion planning. The method is based on the Strength Pareto Evolutionary Algorithm 2 (SPEA2) [7]. The edge-set encoding technique [9] and the constrain-domination concept [11] were used to handle the problem constraints. The method was tested on a real large-scale system and some studies were carried out to analyze the effect of constraints and non-convex regions of the search space on the performance of the proposed method.