



Allocation and sizing of distribution transformers and feeders for optimal planning of MV/LV distribution networks using optimal integrated biogeography based optimization method



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ABSTRACT

Optimization techniques have got much attention for solving complex problems related to different fields. Most of the planning researches deal with primary and secondary distribution systems separately because of complexity of both. This may lead to a local minimum for each but not a global minimum for both. In this paper, we try to reach the global minimum of joined primary and secondary distribution systems planning problem, which is essentially more complicated than planning each of them separately. To overcome such complexity, biogeography-based optimization (BBO) is employed in this work. BBO is a new technique for problem solving, developed by Dan Simon and has attracted wide attention in the last years. BBO is not a reproductive technique and this makes it distinguished from other strategies. Besides, BBO solutions can last or “survive” forever and are modified directly via migration from other solutions, so that BBO solutions directly share their features with other solutions. All of those above mentioned features of BBO algorithm may prove that it can perform efficiently for solving optimization problems and that it might be able to provide better performance compared to other optimization algorithms. In this paper, BBO is employed for solving the problem of optimal planning of a distribution system (OPDS) including both medium voltage (MV) and low voltage (LV) networks and based on uniform or non-uniform load density, where a planning procedure is employed iteratively to find the optimal location and rating of distribution transformers and substations, as well as the type and route of MV and LV feeders. The results are compared with genetic algorithm (GA) and particle swarm optimization (PSO), which indicate that BBO provides better performance in all cases.

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1. Introduction

Distribution systems planning is considered as one of the most important issues in electric power engineering. A distribution system comprises low voltage (LV) and medium voltage (MV) networks. The aim of LV network planning process is to determine the location and size of distribution transformers and LV conductors, such that their capital cost in addition to the line losses cost are minimized. By the same token, the aim of MV network planning process is to determine the location and size of distribution substations and MV feeders, such that the capital cost in addition to the line losses cost are minimized. System reliability indices, such as SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index), also need

to be minimized during the planning procedure. Some planning constraints and limitations need to be satisfied during the planning process. These constraints include the bus voltage level (voltage drop) and actual feeder current which need to be maintained within their acceptable standard ranges.

Optimal planning of distribution systems (OPDS) aims to minimize an objective function composed of the line losses cost, system reliability cost, and investment cost, with the bus voltage and feeder current, as constraints, maintained within their standard acceptable ranges. Since the planning problem is extremely complex, non-linear and discrete, this leads to the importance of employing optimization methods which can deal efficiently with discrete and nonlinear objective functions. In this paper, a discrete model for distribution system cost function is applied to represent the cost of distribution system elements/components as the continuous model severely decreases the solution accuracy. The discrete cost function model is employed in only a few researches in the literature [3,12].

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The planning strategy employed in this paper divides the planning area into regions whose load densities are almost uniform. Each of these regions includes a number of LV and MV zones. Each LV zone comprises a number of load blocks and supplied by an MV/LV distribution transformer, while each MV zone comprises a number of LV zones and supplied by an HV/MV distribution transformer [1]. The dimensions of an LV zone determine the length and accordingly the cost of MV feeder supplying the MV/LV transformer within that zone. So, MV feeders cost is a common component in the objective function associated with both MV and LV networks planning which highlights the importance of simultaneous planning of these networks, where the separate planning decreases the solution accuracy. However; most of the researches in the field of distribution systems planning are focused on MV networks planning [2–10] rather than LV networks [11–16] and only a few researches present integrated planning of both networks simultaneously [1,17–19]. In [17–19], linear and non-linear programming techniques are employed for solving the planning problem; however it is well known that these techniques, as analytical methods, have their own disadvantages of convergence problem, algorithm complexity, as well as the problem associated with handling mixed integer variables. In [1], particle swarm optimization method (PSO) is employed for solving optimal integral planning problem for both MV and LV distribution networks and the results are compared to those obtained using genetic algorithm (GA) and nonlinear programming (NLP) techniques. A recent study [44] shows that both PSO and GA techniques are suffering sometimes from the problem of trapping in local minima, which makes the convergence time slow and leads to poor optimization results.

Various optimization techniques are employed in the literature for optimal planning of distribution systems and are also applied for solving some power system related planning problems, such as capacitors planning, DGs planning, and switches planning [24,25]. These techniques are generally classified into two main categories, analytical and heuristic techniques.

The branch and bound techniques are classical methods which are employed for distribution networks planning [20–23] and can minimize the objective function value. However; these procedures strictly require very excessive computation time due to their combinatorial complexity. This has led to introducing some other techniques, such as the heuristic techniques which are widely accepted in the literature.

Linear programming is considered as the simplest analytical optimization technique and it is applied in case of linear objective function and constraints. This technique has been employed for solving a variety of problems such as, power system planning and operation [26], optimal power flow [27], and economic dispatch [28]. Integer and mixed-integer programming techniques have been presented into the literature because of the discrete nature of some or all variables. These techniques have been employed for solving various problems such as, hydro scheduling [29], TCSC planning [30], and planning and expansion of distribution and transmission networks [17,31].

The majority of power system related problems have nonlinear objective functions and this has led for employing non-linear programming technique (NLP) in optimization of various problems such as, stability analysis [32], optimal power flow [33], and DGs planning [34].

Those previously mentioned analytical optimization techniques are extremely sensitive to initial values and can't deal efficiently with the problem of local minima, where they are usually get trapped in local minima especially in case of complex problems which are nonlinear and discrete. In addition to that, NLP techniques suffer from algorithm complexity as another associated difficulty [35]. All of the above has resulted in introducing another

category of optimization techniques which is so called “heuristic techniques” [3–6,36]. These techniques include, for instance, genetic algorithm (GA) [37], particle swarm optimization (PSO) [38,39], and biogeography based optimization (BBO).

Particle swarm optimization (PSO) is a computational method which is inspired by the movement of organisms in a bird flock or fish school. Genetic algorithm (GA) is a search method which is employed for generating approximate solutions to optimization problems using techniques inspired by natural evolution, such as mutation, selection, and crossover.

Biogeography based optimization (BBO) is an approach to problem solving developed by Dan Simon and has some attributes in combination with other biology-based optimization techniques [40]. Just as GA and PSO, BBO has its own method for sharing information between different solutions. However; GA solutions can last for only one iteration, where the solutions “die” at the end of each iteration. On the other hand, and in spite of the change in a solution's characteristics during the optimization procedure, PSO and BBO solutions can last or “survive” forever. BBO optimization algorithm is the first example of how a natural process can be generalized to solve optimization problems. BBO, as a heuristic approach, uses population of initial solutions, handles integer variables easily along with continuous variables, deals with the objective function and does not need derivatives. These distinctives distinguish its performance from other conventional techniques.

A recent study has been presented in [44] using fourteen benchmark functions [45,46] to evaluate and compare the performance of the optimization algorithms (GA, PSO, and BBO) for solving optimization problems. This performance comparison includes two aspects; convergence time and local minima. The convergence time associated with an optimization algorithm is related to speed that the optimizations are able to travel within a certain time period. The optimization technique that continually get trapped in local minima leads to a slow convergence time and this results in a relatively bad solutions for optimization problems. The above mentioned comparison indicates superiority for BBO algorithm over both GA and PSO; where BBO provides the lowest minimum value associated with all the fourteen benchmark functions. In addition to that, every so often; PSO and GA can't reach the generation limit and get trapped in local minima, while BBO reach the end of generation providing the lowest minimum function value.

In view of the above, BBO algorithm is distinguished and superior over other optimization techniques and can deal more efficiently with the problem of local minima. In this paper, BBO algorithm is employed for solving the problem of optimal planning of a distribution system (OPDS) including both medium voltage (MV) and low voltage (LV) networks and on the basis of uniform or non-uniform load density, which is a complex, nonlinear, and discrete problem. The planning procedure is employed on the planning area presented in [1], where the optimal location and rating of distribution transformers and substations, as well as the type and route of MV and LV feeders are found such that minimize an objective function composed of the line losses cost, system reliability cost, and investment cost. The bus voltage level and feeder current are included as constraints in the objective function. The planning problem results are compared with those presented for PSO and GA in [1] to investigate the efficiency and effectiveness of BBO in the field of optimal planning of distribution systems.

Global description of distribution system model and planning technique is outlined in Section 2. Problem formulation with definition of variables, constraints, and objective function is given in Section 3. Overview of biogeography-based optimization method (BBO) is discussed in Section 4. Solution procedure and methodology for employed planning method are presented in Section 5. The planning problem results and final conclusions are listed in Sections 6 and 7, respectively.

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