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On optimal multistage electric power distribution networks expansion planning

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ABSTRACT

The optimal expansion planning of electric power distribution network to meet system load growth and overcome to pseudo dynamic behavior of network parameters considering a large number of constraints is a hard satisfactory multiobjective optimization problem. This paper implements new developed Imperialist Competitive Algorithm (ICA) for the optimal expansion planning of distribution network. The topology of medium voltage (MV) distribution network as backbone of electric power distribution systems is designed by optimal sizing, siting and timing of medium voltage network components such as HV substation and MV feeders' routes. A multistage expansion planning is proposed to consider dynamic behavior of the system parameters asset management and geographical constraints. In order to reach the global solution an efficient coding is developed for ICA parameters. The Greedy algorithm is used to solve the minimum spanning tree problem to construct a radial configuration of the mesh network. At each stage of the problem the results are fully illustrated either by figures or by tables. A sensitivity analysis is used to show the robustness of the results with respect to ICA parameters variation. The obtained results are compared with GA as well known heuristic optimization tool. The efficiency and capability of the methodology has been tested on an under developed relatively large-scale distribution network.
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1. Introduction

Electric power distribution system is connection point between power transmission network and energy supply to the consumers. Recently because of the importance of the distribution systems in deregulated and smart grid environments from both electric utilities and customers' viewpoint, the operation, expansion and planning of electric power distribution systems has been in more attention. One of the main problems of long-term planning in distribution system is its sensitivity to system parameters such forecasted load, asset management and economical constraints. These uncertainties enforce the planning procedures to encounter with many unwanted problems. To overcome for deficiency of the mentioned problems it is necessary that the planned network is evaluated and resolved at a given periods. A multistage planning procedure can help to solve the non-dynamic expansion planning of the network at the previously work. This paper uses the Imperialist Competitive Algorithm as recently developed heuristic algorithms for the optimal design of large-scale electric distribution systems in order to provide optimal sizing and locating of high voltage (HV) substations and medium voltage (MV) feeder routing simultaneously. In this situation a hard satisfactory optimization problem with different continuous and discrete constraints in large-scale distribution networks should be solved. Because of pseudo-dynamic behavior of mid and long-term planning nature of the problem, a multistage solution is proposed to overcome the system problem arising from parameters variation during planning periods. The aim of this paper is to propose a general framework for large-scale distribution system expansion and planning.

After mid and long-term spatial load forecasting and medium voltage substation placement, the major and important topics of optimal distribution network planning are MV and HV system planning which includes optimal HV substation planning and optimal feeder routing. These two topics may be solve separately or combined with together in a general problem. In this paper a generalized formulation for both optimal HV substation placement and optimal feeder routing problems is developed which directly inserts the constraints of two sub problem in a multiobjective multi constraints optimization problem.

The new algorithm aims to minimize capital investment and operating costs of expanded and new developed installation considering electrical, geographical and other constraints in ODSP (Optimal Distribution System Placement) [1]. The proposed model can modify the existing network and determined the new HV substations as well as new MV feeders' location, size and installation time regarding future load growth.

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Nomenclature

$D_i(0)$	primary location of country i	d	distance between colony and the imperialist
$N_{country}$	number of countries	θ and x	random numbers
N_{col}	number of colonies	λ	energy loss cost factor
N_{imp}	number of Imperialists	R_f	resistance of feeder F_f
$T.C.n$	total cost of imperialist and its colonies	X_f	reactance of feeder F_f
$CostFunction$	the costs function of optimization	m	medium voltage substations (loads) counter
L	number of loads	M	number of MV substations of a HV substation
H	total number of HV substations	$I_{\max}$	maximum loading level of MV feeder in pu
h	HV substation counter.	$AVD_{\max}$	acceptable voltage drop at end of feeders
F	total number of MV feeders	V_{LL}	line voltage in pu
$H_{FC}(S_h)$	fixed cost of HV substation S_h	$MVA(S_h)$	HV substation capacity
$\cos(\theta_f)$	power factor of load in feeder F_f	$I_{LL}(F_f)$	line current of feeder F_f
$F_{FC}(F_f)$	fixed cost of MV feeder F_f		
β and γ	parameters randomly modify colonies search area		

Paper [2] is presented pseudo dynamic methodology approach for optimal placement and determining the service areas of HV and MV substations. Some cost and network improvement functions are used as fitness function.

The complexity of optimal distribution system planning is discussed in literature [3,4]. To find the optimal solution of the modeled complicated problem the ICA optimization algorithm is used [5]. Many attractive paper are prepared about optimal distribution planning [6–9]. In [10] a multistage model to support electric power system planning considering system uncertainties is presented. The method named MIS-REM is expressed uncertainties such as probability distributions and interval values distribution system planning problems. The introduced method can analyze different scenarios including economic and other penalties when predefined market variables are violated. A comparing methodology is used to analysis the effect and interaction of different variables at system planning. Paper [11] is developed a model based on a two-stage procedure that involves mid and long-term planning. The usefulness of the method is on producing possible evolution trajectories which can be defined as satisfactory when a specified risk threshold is accepted by the planner.

The effect of uncertainty in system load is studied using an immunological algorithm at planning of electric distribution networks in [12]. The concept of hybrid energy hub is applied to optimal electric distribution system expansion planning (OEDSEP) in [13]. The problem is decomposed into sub-problems to reach for optimal solution considering system constraints. The main goal of this method is increasing of the system reliability. In [14] some customer and energy based indices are considered system reliability in two stages using differential evolution (DE) optimization method.

Authors of [15] present a dynamic model for distribution system expansion, at the presence of DG that solves total costs and technical constraint of the system simultaneously. The optimal sizing, siting and timing of DG units for peak cutting is merits of the paper. Paper [16] describes a procedure to integrated planning for secondary distribution systems using mixed integer nonlinear programming problem and Tabu search optimization method. In this work the structures of the primary and secondary distribution network and types of structures needed for the system according to topological and electrical constraints of the network is determined. A study for determining relevant distributed generation location of distribution network is done in [17]. An optimization algorithm is based on the Bellman–Zadeh algorithm and fuzzy logic to place the appropriate distributed generation locations. The merit of the study is that it determined DG locations both for distribution network feeders and nodes inside a specified feeder. In [18] an approach for integrated generation and primary–secondary distribution system expansion planning in the presence of wholesale and retail markets is implemented. The presented algorithm divides the problem into six smaller one to reach an optimal planning of a network and maximizing the system reliability using mixed integer non-linear programming. In [19] the number of feeders and their routes, and number and locations of sectionalizing switches of a distribution system are optimized.

Paper [20] is presented an optimization method for MV and LV segments of a distribution network. The major goal is to solve both LV and MV network simultaneously in optimal manner to uniform and non-uniform load areas. This paper is used a method similar to one applied in [1] that location and rating of substations as well as the feeder's routes and types are determined. Consequently, an iterative based method is used for integrated planning of both LV and MV networks using DPSO. According to paper the method shows suitable behavior especially at computation time.

A new model based on planning of electrical distribution networks using particle swarm optimization that considers the possibility variations of the system loads is presented in [21]. The algorithm is applied to obtain non-dominated solutions which indicate different network topologies considering uncertainties in load. Authors of [22] present a branch-exchange algorithm to simultaneously optimize the type of conductor and routes in a radial distribution network. To reach for reasonable simulation times, parallel computing is used. In [10,23] a method to increase distribution horizon planning for a 20 year period is explained. The planning model includes electric distribution network design requirements. Paper [24] proposed a multiobjective Tabu search to solve a multiobjective fuzzy model for optimal distribution systems planning. This algorithm gives nondominated solutions to fuzzy economic cost, level of fuzzy reliability, and robustness maximization as objective function.

A constructive heuristic algorithm to solve DSP problem is proposed by authors of [25]. A local improvement step as well as a branching technique is applied to improve the results. A sensitivity index is used to add a circuit or a substation to the distribution network.

Paper [26,27] presents a model and numerical result for multistage planning of distribution systems with DG. The model involves operational constraints on equipment capacities and voltage limits as well as logical constraints. This paper includes five alternatives and three independent stages [27].

The uncertainties in distribution system planning especially at the presence of DG, such as the uncertain output power of a PEV,

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