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Application of the evolutionary algorithm with memory at the population level for restoration service of electric power distribution networks

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ABSTRACT

The problem of optimising the configuration of electric power distribution networks during changing loadings and in malfunction conditions of the network is a task of multi-criteria optimisation. In the article is presented the co-evolutionary algorithm with memory at the population level, enabling the search for pareto-optimal solutions such as are in the analysed task of network configurations. The drawn up method is used in the organisation of evolutionary algorithm memory uses the theoretical bases of classifying systems. The method presented in the article enables effective search of optimal configurations of distribution networks for various network loadings and also network malfunction conditions. The application of a classification system to the analysed task also enables improvement of the effectiveness of the performance process of designating the scenario of the substitute network configurations. Improvement of the efficiency of the network configuration designation process is obtained using the sought information in the collections of classifiers.

Introduction

The problem posed by the authors is the search for changes in network configuration in conditions of network breakdown, enabling restoration of power supply to the greatest number of network recipient nodes possible, through the effective use of the available network infrastructure. The analysed problem of search for optimal configurations of electric power distribution networks for changing loadings of network elements and for malfunction conditions is a multi-criteria optimisation problem. In this case the sought-after solution is the collection of Pareto-optimal solutions. In the article is presented the co-evolutionary algorithm using memory at the level of organised populations in the form of five subpopulations, the composition of which is changed and organised according to classifying systems' procedures. The drawn up algorithm uses information on loadings and technical economical parameters of the analysed network. Furthermore an important objective of the method is the possibility of using information on values of reliability parameters, operating times of network elements etc. The merit of the proposed calculation method is the possibility of consideration in the analysed distribution network of dispersed generation sources with simultaneous minimisation of time required for the search of the postbreakdown distribution network configurations, which is one of the basic requirements of the proposed method.

Planning a restoration service for distribution systems is a critical task for dispatchers in a control center. Restoration attempts to supply an ample amount of power to nonfaulty out-of-service areas for as many customers as possible while safely operating the distribution system. Reconfiguration is the process of changing the open/closed status of switches and is done for volt/var support, loss reduction, load balancing and restoration. Reconfiguration for restoration is a combinatorial problem involving searching an enormous space of solutions. The problems with integer variables are NP hard, meaning no known algorithm exists to solve these problems in polynomial time. However, reconfiguration for restoration problem is both NP hard and NP and hence belongs to the class of NP complete problems. For such kind of problems, the solution time increases with an increase in the number of integer variables. However, the solution time generally depends on the formulation.

Many approaches have been proposed to solve the restoration problem from different perspectives. For instance, researchers [1,2] incorporated dispatcher's experience and operating rules into an expert system to assist the dispatcher. Related investigations formulated the restoration problem as an optimisation problem

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to minimise the number of unserviced customers [3,4]. This problem has been approached using heuristics [5–7] mathematical programming [8], meta-heuristics (genetic algorithms, tabu search, simulated annealing) [9,10].

In the literature [6,7] may be found attempts to use post-breakdown electric power distribution network configurations methods based on heuristic search algorithms. In such instances assumptions limiting the solution space are applied, which reduces the calculation process. In this case the use of such algorithms for calculations for tasks is hindered by a large number of analysed network nodes. In such cases assumptions may be applied limiting the space or extent of solutions, which reduces the calculation process, but causes search for sub-optimal solutions [11,12].

To solve the problem of network configuration optimisation, use is also made of genetic algorithms in this case the virtue is the possibility of their use with a large number of decision variables and a complex function objective description and limiting conditions. These algorithms with a known structure, loadings and network technical parameters enable designation of connection scenarios in the network. This type of method may be used for the optimisation of the operation of electric power systems with a very large number of elements. In works [13–16] was presented the application of the evolutionary algorithm for the solution of problems of electric power network optimisation. These methods are differentiated by, among others, specialised means of coding [13], various operator recombinations [14,15], methods of scaling application and also methods of reproduction [16–18] based on domination [19].

In the article is proposed the co-evolutionary algorithm with memory managed by classifying system that enables significant increase of effectiveness of speed of the algorithm (on average by 40%). The application of this method is very significant from a practical point of view in the management of distribution networks. The drawn up algorithm also enables the performance of calculations for simulated states of network operation including malfunction statuses. The selection of simulated malfunction statuses is performed through consideration of the reliability characteristics and operation times of network elements. The method proposed by the author of the work is typified by the short time of designating the most rational post breakdown configurations in complex electric power Medium Voltage distribution network structures. The method drawn up may be used in current systems managing the work of distribution networks to assist network operators in taking decisions concerning connection actions in supervised electric power systems.

Theoretical bases of the proposed method

In the applied coevolutionary algorithm the population of solution variants is divided into five subpopulations, which are assessed according to various adaptation functions described in patterns 2–7. After performing succession (supplementation of population with new elements), and before renewed reproduction, these populations are connected and then again divided so that each element of the population may reach the chosen population. The principal purpose of the conducted calculations is the search for the collection of Pareto-optimal solutions.

The application of the method based on the classifier system, whose element is the algorithm with the coevolutionary approach, facilitates the reduction of calculation time (while maintaining the quality of solutions), as against when only the evolutionary algorithm is applied. The classifier system adapted to the analysed task facilitates carrying out an effective process for constructing scenarios for medium tension distribution grids alternative configurations, for the most probable failure modes (determined on the basis of the characteristics of the power system reliability elements). The developed coevolutionary algorithm, an element of the proposed classifier system (using, among others, original genetic operators) facilitates carrying out optimising calculations even for very complex power structures of distribution grids. The sought-after solution is a set of Pareto-optimum solutions. One concept is the separation from the structure of the system of electric power distribution subsystems, of tasks that include enabling making changes in network structures in the event of breakdown and the utilisation of electric power sources within the networks, including renewable resources. A well-known roulette selection method on the remaining fractional part has been used as a selection method. Two specialised reconfiguration operators have been used in the algorithm to create new solutions (crossover probability $p_k = 0.95$, mutation probability $p_m = 0.15$). In order to create new solutions in the algorithm, two specialised reconfiguration operators are applied, the description of which is contained in work [20]. The aim of using of this kind of operators, creating new variants of distribution network configuration, was to examine the change variants effectiveness in the part of the networks close to the supply points, as well as in parts of the analysed network system affected by failures. In the process of evolutionary simulation most frequently crossing and mutation operators are used, enabling directed, but simultaneously random exchange of genetic information.

For the analysed problem the accepted criteria are significant from the point of view of fulfilling the requirements concerning effective use of the network:

- minimisation of the number of connection actions leading to obtaining substitute network configuration,
- maximisation of power delivery reliability level,
- minimisation of the voltage variations in the network nodes,
- minimisation of technical losses in distribution systems,
- minimisation of the power load degree coefficient of the found group of the most loaded network elements,

$$\min_{x \in S} F(x) = \{f_1(x), f_2(x), f_3(x), f_4(x), f_5(x)\} \tag{1}$$

$$f_1(x_j) = \min(n_j - n_0) \tag{2}$$

$$f_2(x_j) = \min\{\max(1 - R_{ik})\} \tag{3}$$

$$f_3(x_j) = \min\{\max(U_i/U_N \cdot 100)\} \tag{4}$$

$$f_4(x_j) = \min\left\{\sum_{l=1}^{g}(\Delta P_l + k_e \cdot \Delta Q_l)\right\} \tag{5}$$

$$f_5(x_j) = \min\left(\sum_{w=1}^{n} P_w \cdot k_w\right) \tag{6}$$

in which: $F(x)$ – vector of function of criterions, S – set configuration of nets, X_j – vector containing information on jth distribution network configuration variant, n_j – number of connection actions, n_0 – number of connection actions in base configuration, R_{ik} – reliability function of i-th node for kth of the year of performed analysis, k – year of performance of node reliability and analysis, U_N – nominal distribution network voltage, U_i – voltage value in i-th reception network node, g – number of line section, P_l – loss of active power in l – this line section, k_e – passive power equivalent, n – number power supply points, Q_l – loss of passive power in l – this line section, k_w – unit costs of energy for power supply points.

Value of affiliation function applied in order to change task minimisation to task maximisation (required with regard to the