ELECTRICAL NETWORK OPTIMIZATION BY GENETIC ALGORITHM

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Abstract: *The article is devoted to the electrical network optimization by genetic algorithms – the optimization method based on the simulation of the biological evolution. This problem is a many-dimensional nonlinear discrete optimization problem, which requires the usage of heuristic or combinatorial algorithms. The mathematical model and algorithm of the given problem are developed. The presented methodology is applied for the IEEE 30-bus test system.*

1. INTRODUCTION

In many countries the generating plants are located on a distance of hundreds of kilometers from centers of loads, therefore any efforts on reduction of electric energy transmission cost even on some percents allow to save significant capital [1-3]. In addition the availability of the optimum plan of power systems development is extremely important for location of new generating plants. The knowledge of the future means of electrical energy transmission will allow to accept more rational solutions.

At present the estimation models are used for a solution of this problem – comparison of several variants of electrical network structure. The application of optimization models is not widespread owing to complicated character of the problem.

However the irrespective of the models their main purpose are the preliminary analysis of possible solutions with the following finding their technological parameters alongside with the additional stability, reliability and quality of the electric power. The optimal variant is the result of the optimum development strategy search.

This problem is many-dimensional nonlinear discrete optimization problem, which requires the use of heuristic and combinatorial algorithms, in particular of evolutionary algorithms as they allow to receive the best solution on a comparison with classical optimization methods.

All evolutionary approaches are based on the modeling of natural mechanisms of inheriting and natural selection. The most known from them are the genetic algorithms. Other realizations of the evolutionary algorithms: evolutionary programming, evolutionary strategies, genetic programming – are less popular though they also are the high-power means for the search of global maximum or minimum of functions.

In this work the application of genetic algorithms for optimization of electrical networks structure are considered. The genetic algorithm is the method of optimization working by the analogy of the evolution of biological kinds in nature. It simulates in artificial systems such properties of natural systems as selection, adaptability to the environment, inheriting by offspring some vital properties from the parents etc. The evolution of a population is considered as a cyclic process of crossing of individuals and change of generations. The given approach works with a population of individuals each of them represents a possible solution of the given problem. Each individual is evaluated by a measure of fitness, which is the value of the objective function for this solution. From a mathematical point of view the genetic algorithms are a variety of optimization methods joining features of probabilistic and deterministic optimization algorithms.

In order to analyze the possibility of application of genetic algorithms for problem like this the mathematical model of the problem is developed, the accepted assumptions are appreciated and the algorithm of the solution based on a simple genetic algorithm is offered. This algorithm is tested on the IEEE 30-bus system.

2. PROBLEM FORMULATION

The criterion is to find the optimal electrical network of minimum costs. It can be achieved by adding new circuits to the existing network subject to specific constraints. The objective function of the problem consists of two components: the costs associated with the network development (construction of new transmission lines), and the costs associated with active power losses.

The network costs will increase with putting into operation new additional circuits and at the same moment costs of losses will decrease and on the contrary.

The mathematical statement of the problem is the following:

- Objective function
$$F(L) = C_L + C_{\Delta P} \to \min , \quad (1)$$
- Subject to equality constraints
  - active power flows equations
$$\sum_{i=1}^{n} P_{gi} - \sum_{i=1}^{m} P_{di} - \Delta P_{\Sigma} = 0 , \quad (2)$$
  - reactive power flows equations
$$\sum_{i=1}^{n} Q_{gi} - \sum_{i=1}^{m} Q_{di} - \Delta Q_{\Sigma} = 0 , \quad (3)$$
- And subject to inequality constraints
  - maximum number of circuits
$$\mathbf{L} \le \mathbf{L}_{\max} , \quad (4)$$
  - line capacities limits
$$I_i \le I_{i\max} , \quad (5)$$
  - bus voltages limits
$$U_j^{\min} \le U_j \le U_j^{\max} , \quad (6)$$

The components of the objective function:
$$C_L = E \cdot \mathbf{L} \cdot \mathbf{C} , \quad (7)$$
$$C_{\Delta P} = C_0 \cdot \tau_{\max} \cdot \Delta P_{\Sigma} , \quad (8)$$

were C_L – cost of new transmission lines construction; $C_{\Delta P}$ – cost of active power losses; P_g – active power generation; P_d – active power demand; Q_g –reactive power generation; Q_d – reactive power demand; ΔP_{Σ} – total active power losses; ΔQ_{Σ} – total reactive power losses; I_i – line capacity of the branch i, where i is a branch number according to the scheme of electrical network; U_j– voltage magnitude at bus j; **L** – array of new transmission lines; $\mathbf{L}_{\max}$ – array of maximum number of new transmission lines; **C** – array of new transmission lines costs; E – norm of discount; C_0 – cost of the active power losses; τ_{max} – number of hours of maximum losses.

3. THE PROPOSED ALGORITHM

The proposed algorithm of the optimization of electrical network is based on the simple genetic algorithm [4]. It can be formulated as follows:

Step 1 – The construction of the initial population. It is obtained by randomly drawing among possible values of variables eq. (4). The individual (solution of the problem) represents set of decimal variables associated with new circuit additions.

Step 2 – The fitness computation for individuals of initial population. It is equal to the objective function for this solution. As for the active power losses calculation the expression with rated voltages can be used as well as the power flow algorithm. The genetic algorithm can be also applied for this purpose [5].

Step 3 – Genetic operators realize the evolutionary process of a population.

Step 3.1 – The selection of the parents. Roulette operator makes the selection of candidate individuals to participate in reproduction.

Step 3.2 – The crossover of individuals. The simple single-point crossover is applied with probability P_{cr} for obtaining new solutions.

Step 3.3 – The mutation of individual. One selected gene in each individual is mutated with probability P_{mut}. New value of this gene is generated randomly in limits specified by eq. (4).

Step 3.4 – The objective function computation for every individual of new population by eq. (1). The best individuals among parents and their offsprings are kept to constitute the new generation.

Step 4 – The checking of the termination criterion (maximum number of generations). If the number of generations is exceeded the specified maximum the evolutionary process is completed otherwise go to Step 2.

4. SIMULATION AND RESULTS

The applicability of the algorithm was tested on the IEEE 30-bus system consisting of 30 buses, 41 branches and 10 additional branches. The simulation is carried out with Matlab tools.

Main 41 branches of the electrical network are understood already as existing transmission lines. New 10 lines are considered as additional, which construction is possible taking into account technical, ecological and other restrictions.

The problem of the network optimization was considered in the following variants:

- optimization of the existing nonoptimal electrical network,
- optimization of the electrical network under new electric power demands.

The obtained results for first variant demonstrate the reduction of losses (Fig. 1). For the initial scheme the total losses of active power were 2.444 MW and after optimization for optimal network – 1.349 MW. That is 1.095 MW is saved for test system.

The next variant of the given problem is the network optimization under changed electrical power demands. In this case the situation was simulated when demands of all enterprises of the region are increased by 10 %.

As shown in Fig. 2, with new power demands the optimum scheme of the electrical network differs from obtained previously. Here three new parallel branches 3, 11 and 14 are added into scheme. At the same time the adding of the branch 36 is inexpedient.

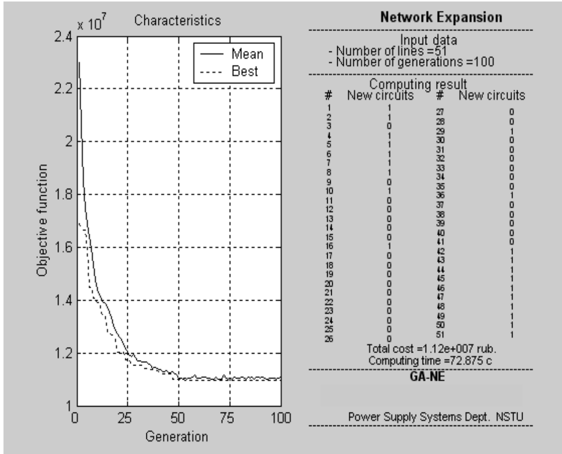

Fig. 1. Result window for optimization of the existing electrical network

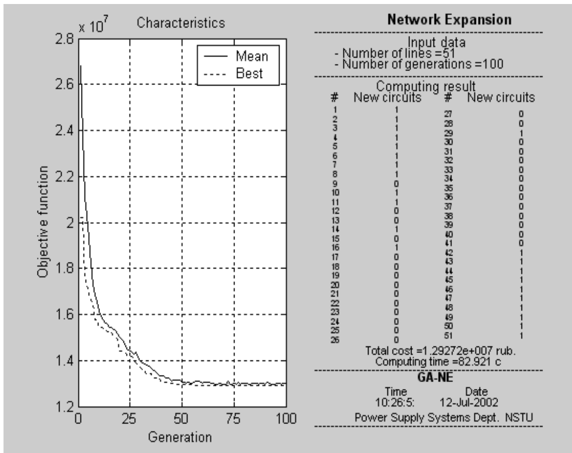

Fig. 2. Result window for optimization of the electrical network with uniform load increasing

One of the actual variant of the problem is the search of optimal scheme under local changes of power demands. Such statement simulates development of the electrical network because of the local load inreasing (only in specified buses).

The situation is considered in which the loads in buses number 10 and 19 are increased by 10 %, and in buses number 9 and 28 new enterprises are placed into the operation which requires 6.2 MW, 1.6 MVar and 9.4 MW, 3.5 MVar accordingly.

The local modification of power demands is not determinative to the optimization process (Fig. 3). Only two new parallel branches 3 and 11 are added into scheme on a comparison with existing structure of the electrical network. As well as earlier, all additional lines are used in new optimal network.

From the obtained results it is possible to make a conclusion about relatively fast convergence of the given process. Also it is necessary to mark the independence of the offered approach from an initial value. In addition the possibility of the application of the decimal variables excludes necessity of the approximation them up to the nearest integer. Therefore the accuracy of the proposed approach is higher.

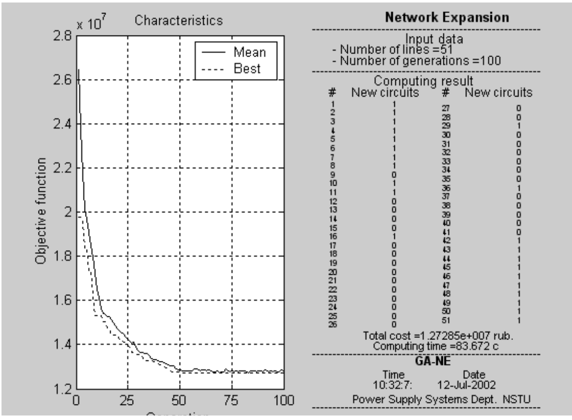

Fig. 3. Result window for optimization of the electrical network with local load increasing

As for all obtained results, in the considered cases it is possible to make a conclusion about the priority in construction of new transmission lines. It testifies to some underestimation of new lines construction costs. It is necessary to note, that it is the especially particular case existing in specific concrete situation in power system. Subsequently it is possible to analyze the influence of cost parameters on the problem solution, for example to define price limits until the construction of new lines still remains profitable.

5. CONCLUSIONS

The analysis of the search process and the solutions allow to mark that the effectiveness of the genetic algorithms for given problem based on the following factors:

- simple computational scheme,
- combinatorial nature of the problem,
- absence of any special requirements for continuity, differentiability of optimization criterion,
- discrete character of variables and therefore the application of the decimal representation of the variables,
- simple and effective method of keeping the variables in the specified limits.

Finally it is necessary to underline the possibility of using of evolutionary algorithms in other modifications of this problem, namely: determination of the optimum structure of a new network, expansion of an existing network at new load levels.

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