VOL. 15, NO. 23, DECEMBER 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MODIFIED GENETIC ALGORITHM TO DETERMINE THE LOCATION OF THE DISTRIBUTION POWER SUPPLY NETWORKS IN THE CITY

I. Fedorchenko[1], A. Oliinyk[1], J. A. J. Alsayaydeh[2], A. Kharchenko[1], A. Stepanenko[1] and V. Shkarupylo[3]
[1]Department of Software Tools, National University «Zaporizhzhia Polytechnic», 64 Zhukovskoho str., Zaporizhzhya, Ukraine
[2]Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia Center for Advanced Computing Technology, Universiti Teknikal Malaysia Melaka
[3]Department of Computer Systems and Networks, National University of Life and Environmental Sciences of Ukraine, Heroyiv Oborony str., Kyiv, Ukraine
E-Mail: evg.fedorchenko@gmail.com

ABSTRACT

The problem of combinatorial optimization in relation to the choice of location of power supplies in solving the problem of development of urban power distribution networks is considered. Two methods of placing power supplies and securing consumers for them have been developed to solve this problem. The first developed method is to place power supplies of the same size, and the second - different sizes. The fundamental difference between the created methods and the existing ones is that the proposed methods take into account all the material of the task and have specialized ways to encode possible solutions, modified crossbreeding and selection operators. Proposed methods effectively address the problem of low inheritance, topological impracticability of the found solutions, as a result of which the execution time was significantly reduced and the accuracy of calculations increased. In the developed methods the absence of the account of restrictions on placement of new power supplies which has allowed to solve a problem of application of methods for a narrow range of tasks is realized. A comparative analysis of the results obtained by placing power supplies of the same size and known methods was performed, and it was found that the developed method works faster than known methods. It is shown that the proposed approach provides a stable convergence of the search process for an acceptable number of steps without artificially limiting the search space and the use of additional expert information on the feasibility of possible solutions. The obtained results allow to offer effective methods for improving the quality of decisions made on the choice of location of power supply facilities in the design of urban electricity.

Keywords: genetic algorithm, power supply, evolutionary algorithm, power supply system, combinatorial analysis.

INTRODUCTION

Recently, the demand for electricity has increased, as a result of which designers of urban power supply systems are dealing with a large amount of input information [1]. Processing and analysis of large arrays of information and the high dynamics of their parameters have led to the need to develop new methods of placement of power supply facilities [2].

The efficiency of the systems of production, transmission and distribution of electricity is largely determined by the design solutions that were used in the process of forming electrical networks and systems. In the general case, the task of designing the development of electricity systems and electrical networks is to develop and economically justify technical solutions that provide reliable and high-quality energy supply to electricity consumers, taking into account all technical, technological, environmental, social and other constraints [2].

When designing urban electrical networks, the task of choosing a rational configuration of the power supply system arises. Under the configuration of the power supply system understand a certain relative position of the elements of the power supply system (cable, overhead lines, transformer and power substations, etc.), the relationship of elements in the power supply system, connection of elements in the form of a structure [2].

Power supply of all facilities, on the one hand, must be sufficient in capacity and meet the requirements of reliability of power supply to consumers of different categories, and on the other - economically feasible. The task of choosing the actual location of power supply facilities is a task with hundreds of alternative solutions, and planners must find the solution that works best. Due to the complexity of the task of choosing a rational configuration of the grid, has not yet found its detailed consideration and solution to the problem of placing several power supplies of different and identical sizes and simultaneously fixing consumers for these power supplies. Therefore, the task of placing power supply (PS) facilities at the design stage is relevant [3].

Existing models and algorithms for solving the problem of optimal placement use a discrete programming device, with which the problem is solved by full or partial search [3], which slows down the process of finding the optimal result. An alternative to this approach is the use of heuristic algorithms that are highly efficient and provide the detection of the optimal solution throughout the search space for an acceptable number of steps. This article proposes a modified genetic algorithm for solving a discrete problem of placement of power supply facilities and the simultaneous assignment of consumers to them.

ANALYSIS OF LITERATURE DATA AND PROBLEM STATEMENT

This paper considers and investigates the problem of the first stage of creating a rational configuration of the power grid, namely, the problem of placing several PS in the distribution network and the simultaneous fixing of consumers for the selected PS. The solving problem refers to the problems of combinatorial search, to the formulation in which the optimization problem is solved. The essence of the task is to search for all possible options for placement of PS and assign them to consumers, then their evaluation and selection of the best option [4].

All methods of combinatorial optimization can be divided into: exact and heuristic. Exact methods include: the method of complete search, the method of implicit search, the method of branches and boundaries, and others. One of the types of heuristic algorithms are the recently popular genetic algorithms (GA) and artificial neural networks (ARNs). Therefore, we consider the solution methods for constructing a rational configuration of power supply systems [4].

In [5] a description of the method of determining the number and location of new transformer and distribution substations (DS), the construction of which is necessary to provide all new consumers with the ability to connect to the power supply network. The method proposed by the authors is based on the method of k-means. The basic idea is that initially from a set of possible places of construction of new transformer and distribution substations N points which will be the centers of clusters (centroids) are randomly chosen. Then there is a redistribution of consumers in clusters on the principle of the smallest distance from the center of the cluster. In other words, a consumer belongs to that cluster if for this consumer the distance to the centroid is smaller than to any other. Next, for each of the obtained clusters, its loading center of gravity is calculated and from the set of possible construction sites for new substations, the point closest to it is selected. This point is taken as a new centroid, then there is a redistribution of consumers according to the principle described above. The clustering process ends when, in the next step of the algorithm, the coordinates of any of the centers of the clusters do not change.

The advantage of the proposed method by the authors is simplicity and low computational costs.

The disadvantage of this method is the need to pre-determine the number of clusters, as well as the dependence of the result of the decision on the initially selected cluster centers.

In [6], a method for selecting the location of new transformer substations (TS) using separate clustering is proposed. Initially, all consumers are combined into one cluster and the possibility of building transformer substations at some point from the allowable set is tested. The test is performed in such a way that the connectivity conditions for all consumers in the cluster are met. If this condition is met, the algorithm stops working, and the selected point is determined by the construction site of a new transformer substation. If the above condition is not met, the source cluster is divided into two clusters according to this rule. A pair of consumers is determined from a set, the distance between which is greater than between any other consumers of this set. Each of the selected consumers forms a cluster and is its centroid. These consumers are excluded from further consideration. Then again one pair of consumers is determined, the distance between which is greater than between any other consumers. These consumers are distributed on previously formed clusters: the first to the cluster is the object that is closest to one of the centroids, and the second consumer belongs to another cluster. This procedure is performed sequentially until all consumers are removed from consideration. If the number of consumers is odd, then the last consumer belongs to the cluster to the centroid of which it is closer. Which is closest to one of the centroids, and the second consumer belongs to another cluster. This procedure is performed sequentially until all consumers are removed from consideration. If the number of consumers is odd, then the last consumer belongs to the cluster to the centroid of which it is closer. Which is closest to one of the centroids, and the second consumer belongs to another cluster. This procedure is performed sequentially until all consumers are removed from consideration. If the number of consumers is odd, then the last consumer belongs to the cluster to the centroid of which it is closer. The method continues to work until the condition of the possibility of building a new TP and connecting all consumers to it is fulfilled for all selected clusters.

The proposed method based on separate clustering refers to hierarchical clustering methods, the advantage of which, compared to the method of k-means, is the absence of the need to specify the number of clusters.

The disadvantage of this method is the high computational costs and, consequently, the possibility of its application only for clustering a small number of objects.

In [7], determining the location of the power supply is based on the laws of classical mechanics (determining the center of gravity). There are a number of mathematical methods that allow analytically to determine the conditional center of electric loads (CEL). The center of electrical loads is a geometric point, the position of which characterizes the distribution of loads (masses in the body or mechanical system). The problem is solved under the assumption that the load of any object (consumer) is evenly distributed over its area. Loads in this case are represented in the form of circles with radii proportional to the values of loads (power consumption).

The described method of finding CEL is simple and clear, the error of calculations by this method does not exceed 5-10%. This approach assumes that the costs are not proportional to the distances, but to the squares of the distances from the power source to the consumer. This assumption determines the error of the method, but at the same time gives a fairly simple formula for determining the CEL [3].

In addition, the publication [3] assumes that the CEL is not a constant point and that it tends to shift over time due to changes in power consumption by individual receivers, due to changes in socio-economic and environmental conditions, etc. Therefore it is more correct to speak not about the center as some stable point, and about a zone of scattering of the center of electric loadings. Obviously, the meaning of the proposed method is to minimize the total distance between the TP and consumers, taking into account the amount of power of each consumer. This does not take into account the real conditions of the transmission line and the restrictions that exist on the territory for the placement of TS.

In [8] the method of placement of TS and DS is described, based on the choice of one of several possible variants in the conditions of multicriteria using the method of complete search. In this case, several possible locations of TS and DS and approximate routes of transmission lines for each option are specified and then the best is selected from these options.

The algorithm proposed by the authors is simple and easy to implement and guarantees that the best option for placing TS and DS will be found, but this may take an unacceptably long time. It is logical to conclude that a complete search of plans is a very undesirable way to solve combinatorial problems, a kind of last resort in the absence of more practical algorithms. You should use any opportunity that allows you to either significantly reduce the search, taking into account the specifics of a particular task, or in general, if possible, to abandon the search and use other approaches to solving the problem and other methods of solution.

In [9] the development of the method of optimal placement of DS for small-dimensional problems taking into account voltage losses from central substation (CP) to remote consumers. The ant algorithm was chosen by the authors as the optimization technology. The developed method is based on the behavior of ants in search of the shortest paths to food, as food in this work is DS. If an ant finds food in the process of searching, then, returning to the anthill, it leaves traces of its pheromone on the way back. As a result of a successful search for food, several ants will form trails with a higher concentration of pheromones than in other search spaces. Most likely, other ants will follow this path. As a result, the shortest, optimal path to the food source will be formed. In the context of this solution, the places with the highest concentration of pheromones are the sets of variables with the best solutions to the problem. The advantage of this method is the higher speed of finding the optimal solution than traditional methods and is characterized by scalability and flexibility with increasing dimension. However, the proposed method has a complex code and a large number of customizable parameters.

In [10] the solution of the problem of planning the power supply system is presented, namely the determination of the optimal size and location of the TS while satisfying the requirements of consumers with minimal updating of the system. The developed algorithm is based on simulation of annealing. To obtain the optimal solution, an ordered, random search is used based on the real physical process that occurs during the annealing of metals. The annealing method is based on the natural process of transition of a substance from a liquid state to a solid state, as a result of its heating and slow cooling the optimal structure is formed. The cooling criterion is the main point of the annealing simulation optimization method. In fact, this method depends on three variables: initial temperature, cooling rate and final temperature. The process is initiated from the point of possible placement of power supplies. After upgrading the power supply system, new possible solutions will be identified based on the probabilistic eligibility criterion.

The proposed algorithm has a fairly simple implementation and a huge advantage is the property of avoiding the "trap" in the local minima of the optimized function and continue the search for the global minimum.
The disadvantages include the need for multiple tests to select the correct parameters of the algorithm. The result of this algorithm strongly depends on the selected values of the parameters, which is unacceptable for solving this problem.

In the publication [11] to expand the distribution network uses a hybrid method of branches and boundaries. The authors solve the problem of optimizing the location of TP, as well as the design of medium voltage networks with a justification of the routes of electricity transmission from power sources to consumers. In this case, the method of branches and boundaries is used to solve the combinatorial optimization problem. This method is a modification of the full search algorithm, which guarantees the accuracy of the result of its work. The essence of the method is to build a tree of complete search and cutting off unpromising branches of the solution as it is bypassed, which significantly reduces the time of its operation. The method of branches and boundaries reduces the time to find the optimal solution due to the fact that when entering each node is the upper and / or lower assessment of a possible solution, which will lead to bypassing the subtree, the root of which is the current node. According to the received estimation the conclusion is made - if the best of possible decisions is worse than current, the given subtree (branch) is cut off and the bypass proceeds from the following knot of the same level at which cutting was made.

The advantage of this method is that it allows to obtain a solution in the form of a global extremum by reducing the number of steps of the method of branches and boundaries.

The main disadvantage of the proposed method by the authors is the need to completely solve the problem of linear programming. For large-scale tasks, this requires significant and, to some extent, unjustifiably time-consuming.

In the publication [12] to solve the problem of placement of PS proposed the following method: it is proposed to divide the route of laying the transmission line into zones that have different cost indicators. At the boundaries of the zones are the points of transition from one zone to another. You need to build the optimal route of the transmission line that connects the start and end point. In this paper, it is proposed to solve this problem by dynamic programming, in which to find the optimal solution, the planned operation is divided into a number of steps (stages) and planning is carried out sequentially from stage to stage, and the choice of solution at each stage is based on the interests of the operation. The authors chose the gravitational search algorithm as an optimization technology, which is based on the concept of universal gravitation. According to this concept, the bodies with the largest mass have the greatest gravitational force of other bodies in space. Subsequently, all particles in space are attracted to the largest centers of mass. As for the particle optimization algorithm, these are modes with sets of variables. In the process of completing the task, the most successful solutions attract the closest, thereby increasing their weight among all possible options.

The advantage of the method proposed by the authors is its simplicity and ease of implementation to this problem, and it has a high degree of random generation of variables, which provides coverage of the entire search space. The disadvantage of this method is the poor ability to locally find a solution and the need to fine-tune the initial parameters of the method.

The publication [13] considers the problem of choosing the optimal power and optimal location of power sources (substations) in electrical distribution networks. The work uses a taboo search to select the optimal location of the substation. This method is based on the descent mechanism, which moves to the optimal solution. The algorithm has a list of prohibitions that contain a number of solutions found in previous iterations. Due to this algorithm does not focus on finding repetitive solutions. To get out of the local optimum, a mechanism of deterioration of results is provided.

The advantage of the method proposed by the authors is that it reduces the time for processing primary data and has a reasonable time to complete the task. The disadvantage of this method is that it has a large number of customizable parameters and a low accuracy factor.

The publication [14] presents the following task: there is an existing distribution network, over time, new load nodes are added in the area, the location of new nodes and possible locations of substations. The network reconfiguration procedure should be performed so that the newly designed distribution network is optimal in terms of costs. To do this, the paper proposes a modified genetic algorithm. The main idea of the proposed approach is to present the characteristics and properties of possible solutions using binary code and the formation of a vector containing binary chains of properties of the solution. It is obvious that such a vector to some extent corresponds to a simplified mathematical model of the genotype of a biological organism, which contains complete information about this organism. This fact allows the use of basic genetic crossbreeding operations, which lead to the formation of new solutions with new properties. The formation of possible solutions is carried out cyclically on the basis of previous generations using the genetic operations of crossover (crossing), inversion and mutation, which are applied randomly according to stochastic laws. At the same time, priority is given to solutions characterized by the highest values of the efficiency evaluation function, which guarantees a gradual improvement of the quality of the proposed solutions.

The advantage of this method is that it has the simplicity and transparency of the implementation of encoding and decoding information, as well as reduced likelihood of looping the search process in local optimums.

The disadvantage is that it has a high iterative algorithm, a significant dependence of search efficiency on the selected parameters, as well as a high probability of premature convergence of cyclic search.

In [15], an artificial neural network (ANN) was proposed to solve the problem of choosing the optimal configuration of the electrical distribution network. As a target function, a function is proposed that takes into account the capital costs of construction and annual costs of operation of such a network. The use of ANN is widely known and well suited for this task. ANN is a directional, weighted graph, the vertices of which simulate the functioning of biological neurons. The vertices receive the input signals and at a sufficiently large value of their weighted sum will convert them into an output signal. ANN training is performed on the basis of empirical data and consists in calculating the coefficients of connections between the vertices, which determine the strength of the incoming signals. In the work to solve the problem, a neural network with inverse error propagation was developed.

The advantage of this method is the ability to reproduce complex nonlinear dependencies with a large number of input parameters. This method has the ability to adapt to changes in the input data, which allows them to work properly all the time.

The disadvantage of this method is that the time spent on the training procedure often does not allow the application of this method in real-time systems. When applying the proposed model, there is a problem of preparing a training sample, associated with the difficulty of finding a sufficient number of training examples.

In [16], a method for finding the optimal location of the TS based on a rough random search is proposed. This is the simplest and at the same time the most famous random search algorithm, consisting of a uniform random "throwing" of points in the search space. The method of random search has two advantages. First, it is suitable for any objective function, regardless of whether it is unimodal or not. Secondly, the probability of success in attempts does not depend on the dimension of the considered space. Although this method does not directly find the optimal solution, it creates favorable conditions for the use of other search methods in the future. Therefore, it is better to use in combination with one or more methods of other types.

In [17], a method for finding the location of DS in combination with the approach of taking into account the sensitivity to losses power. This method is based on a search with prohibitions, which belongs to the class of local search strategies. The main idea of the search technique with prohibitions is to avoid cycles (visiting the same solutions) in the search process, using a list of prohibitions, which allows you not to stop at the local optimums. The list of prohibitions stores information about the search history in the form of a fixed number of viewed solutions. The decision on the next iteration depends not only on its quality, but also on information about the search history. Decisions saved in the list of prohibitions are taboo, and they cannot be selected when analyzing the neighborhood. In this technique, the complete neighborhood of the current solution is generated on each iteration. The best solution (not taboo) from the neighborhood is chosen for the next generation. The paper also concluded that

The advantage of this method is that it allows you to continue the search after finding the local optimum, thereby expanding the search space, in the hope of finding a solution close to optimal.

The disadvantage is that the proposed method stops when the local optimum is reached. To solve this problem it is necessary to look for the global optimum. Obviously, the global optimum is also local, but to successfully find solutions it will be necessary to somehow move from one local optimum to another, which is not convenient.

The analysis of works [4 - 17] allows to state that carrying out of researches on optimization of methods of placement of objects of power supply is rather actual task. A comparative analysis of the exact and heuristic methods was performed and it was found that the exact methods showed good results, but they have one very serious drawback. The execution time of precise methods increases exponentially with increasing dimension of the problem. To solve this problem, this is unacceptable, because the calculations are a large amount of data on consumers, PS and sizes. Also a problem of classical methods is the difficulty in interpreting the obtained data. Heuristic methods with increasing dimension of the problem give better results compared to other methods in a reasonable time, but it reduces the accuracy of calculations. Also a significant disadvantage was that that a large number of heuristic methods were created to solve a small number of problems, usually from one area of knowledge. As a result, the application of any method to solve another problem of placement of PS becomes very difficult.

Therefore, in order to solve the problems that arise when using the studied methods, it was decided to develop a modification of the GA to improve the accuracy and maintain the speed of calculations. The developed method should have proposed specialized genetic operators of crossbreeding and selection, which will effectively solve the problem of low inheritance, topological impracticability of the solutions found, resulting in significantly reduced execution time. Also in the created method the absence of the account of restrictions on placement of new PS should be realized that will allow to solve a problem of application of methods for a narrow range of tasks.

THE PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of the study is to develop a mathematical model for solving the optimal problem placement of power supplies of the same and different sizes and simultaneous fixing of consumers in the power supply system on the basis of heuristic methods

To achieve the goal of the study it was necessary to solve the following tasks:

- To develop a genetic method of placing several power supplies of the same size and simultaneously assigning consumers to them.
- To develop a genetic method of placing several power supplies of different sizes and at the same time fixing consumers for them.
- To present an experimental study of the proposed genetic methods of placement of PS.

DEVELOPMENT OF GENETIC METHODS FOR PLACING PS OF THE SAME AND DIFFERENT SIZES IN A DISTRIBUTED ELECTRONIC NETWORK

This paper considers the problem of substantiation of the development of complex distribution systems of power supply as a hierarchy of tasks, at the first stage of which the tasks of choosing a rational configuration of the power grid are solved. One of the main tasks of the first stage in the construction of a rational configuration of the power grid is the placement of n PS and assigning consumers to them.

Suppose that in the Cartesian coordinate system on the plane a system of points with coordinates $\{x_i, y_i\}$, $i = \overline{1, m}$ is given, which correspond to the places of connection of loads (consumers). The set I = {1, 2,…, m} is the set of connection points of load nodes (consumers). Each load node is characterized by the total power consumption P_i. The set $\{P_i\}$ determines the amount of power consumption. Therefore, the total power consumption of $P_{sum.con}$ by all consumers is determined by formula (1) [18]:

$$P_{sum.con} = \sum_{i=1}^{m} P_i. \tag{1}$$

Suppose that a system of points with coordinates $\{x_j, y_j\}$, $j = \overline{1, n}$ of possible locations of power supplies constituting the set J = {1, 2,…, n} is also given in the Cartesian coordinate system. In the considered statement it is assumed that this number n is consciously more than practically necessary number of places of placement of PS. So, for example, in a problem it is necessary to define no more than 6 places of placement of PS, and possible places of placement it is possible to specify some tens [18].

We present a typical series of electric power sources (power supplies) used to solve the problem. Let this typical series have the form of the set $\{P_1, P_2,…, P_t\}$, where t is the number of different sizes of PS.

Hence, the total power Psum.give given to the PS is determined by formula (2):

$$P_{sum.give} \geq P_{sum.con} + P_{\min}, \tag{2}$$

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where P_{min} is the power of the smallest PS involved in solving this problem.

The second condition for choosing $P_{sum.give}$ is that this value contains an integer number of terms, and each term should be equal to the amount of electricity production considered in this problem, the sizes of PS [18].

Consider the example of a simple problem of constructing a rational configuration of the power grid [19]. Under the condition of the problem, the total power consumption is 23 MW and it is known that the typical series includes power supplies of the following capacities: 4 MW, 6 MW, 12 MW. Therefore, according to the given typical series Psum.give = 24 MW [19].

Based on the found value of $P_{sum.give}$ and the specified sizes of power supplies, we will find all possible combinations, provided that one PS at one of the possible points (this is a very important condition, otherwise you just need to add to the standard series used other PS, the power of which can be doubled, tripled, etc. depending on the sizes used first). According to the known data we will formulate some set of variants of combinations of quantity and standard sizes of power supplies for a covering of $P_{sum.give}$: $4 \cdot 6 = 24$, $6 \cdot 2 + 4 \cdot 3 = 24$, $12 \cdot 1 + 4 \cdot 3 = 24$, $6 \cdot 2 + 12 \cdot 1 = 24$, $6 \cdot 4 = 24$, $12\ \ 2 = 24$ [6].

In embodiments, the first product multiplier indicates the power in MW of the power supply, the second multiplier shows the number of power supplies of a given size. As follows from the options described above, in the first case, the placement of the PS will require six possible locations, in the second five, etc., and finally, in the latter case, you will need two possible locations of the PS [19].

We number all these options and get the set V = {1, 2,…, v}. Each element of this set uniquely determines the number of locations for each size of PS, which participates in this variant of power supply [19].

Taking into account all the above, we have the following optimization problem: you need to choose the most economical option for placing PS, taking into account the cost of delivery of electricity to consumers, and you should choose the following parameters:

- Option i from the set V = {1, 2,…, v} possible combinations of the number and size of power supplies.
- Locations of power supplies from the proposed n possible locations.
- For each consumer, determine - which power source it will be attached [17-19].

The general statement of the problem is reduced to the minimization of the objective function (OF) F, which expresses the cost of electricity transmission from production points to consumption points (3):

$$F = \min\left(\sum_{i\in I}\sum_{j\in J} P_i C_{ij} d_{ij}\right), \tag{3}$$

where P_i is the value of the transmitted power; d_{ij} - distance from power supply j to consumer i; C_{ij} - specific reduced costs for transmission of a unit of power per unit of distance [17–19].

It is assumed that the electrical network does not limit the transmission of power from the power supply to the consumer [19].

In the future, we will assume that the electrical network has a radial structure, which is characteristic of the operation of many power supply systems, as well as the specific costs $C_{ij} = 1$, ie the objective function takes the form (4) [17-19]:

$$F = \min\left(\sum_{i\in I}\sum_{j\in J} P_i d_{ij}\right), \tag{4}$$

The distance from the PS to the consumer is calculated according to the Euclidean metric by formula (5):

$$d_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}, \tag{5}$$

where (x_i, y_i) - coordinates of the consumer $i = \overline{1,\ m}$; (x_j, y_j) - coordinates of the location of PS $j = \overline{1,\ n}$ [19].

In the classical case, this problem is solved using the methods of combinatorial analysis. Any combinatorial calculations require a preliminary analysis of the complexity of solving the problem and the algorithms used to solve it. Problems are usually evaluated in terms of dimensionality, ie the total number of different options, among which you need to find the best solution, and algorithms are evaluated in terms of complexity. Thus, the decisive problem can be attributed to the class of large-scale problems [20].

In addition, in this problem there is a need to solve the optimization problem, optimizing several parameters at once, ie the problem belongs to the class of multiparameter optimization problems [20].

The use of classical methods for solving overcome problems does not lead in this case to solving the problem in a reasonable time. Therefore, there is a need to apply new approaches to solve the problem. To solve this problem, it was decided to use evolutionary methods [20], which in comparison with the methods of complete search will reduce computational costs and solve the optimization problem faster and more efficiently.

The first method created is to place a PS the same standard size and simultaneous fixing of consumers for them. Consider below in more detail the structure of the developed method of placing power sources of the same size.

Formation of the initial population. The formation of the initial population is the first step in the implementation of the genetic algorithm. The initial population is created by random generation of chromosomes, and chromosome fitness is not an important indicator at this stage. Thus, the initial population may not

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be competitive at all, but in the course of the algorithm the population will become more adapted [21].

The genetic algorithm processes one population in one step. The population G (t) in step t is a finite set of lines (6):

$$G(t)=\left(S_1^t, S_2^t, ..., S_K^t\right), \quad (6)$$

where S_K^t - chromosome (individual); K is the number of chromosomes in the population, and chromosomes in the population should not be repeated [22].

The formation of the initial population is associated with the representation of the parameters of the problem in the form of chromosomes, in our case in the initial population must be present all possible locations of PS, ie all points of the set J = {1, 2,…, n}. The chromosome represents some solution to the problem. As a gene - a unit of hereditary material responsible for the formation of alternative features of the chromosome, take the location of the PS. The length of the chromosome will be equal to the number of possible locations of the PS. Each chromosome contains n interconnected genes that follow each other, represented by formula (7):

$$p(x)=\left(p_1, p_2, .., p_n\right), \quad (7)$$

where p_n is the location of the PS [22].

The gene of the individual S_k^t will be denoted by g_k^t by formula (8):

$$g_n^t = g\left(S_k^t\right)=\left(g_1\left(S_k^t\right), g_2\left(S_k^t\right), ..., g_n\left(S_k^t\right)\right), \quad (8)$$

Where S_k^t is an individual; t - some point in time of the evolutionary process; k is the number of the individual k = {1, 2,…, K}.

Consider the option of power supply, where PS of the same size, which fully cover the needs of electricity consumers. Suppose it is N - the number of identical PS involved in the power supply of the area, and the number P - the size of the PS. The chromosome consists of two lines: the value and possible location of the PS. The value string is a bit string and the number of units in this string should be equal to the number N, ie the number of required PS for the power supply of the area. One means that there is a PS in this place, and zero means that it does not exist. The second line indicates where the selected PS is located.

In the process of genetic search, there may be a situation of significant variance in the values of the target function of the chromosomes of the population, which leads to an excessive reduction in the probability of selection of most chromosomes for crossing [23].

To overcome this problem, it is necessary to bring the value of the target function of chromosomes in the population to a single order. To do this, the objective function F is mapped to the fitness function f by recalculating its values for each chromosome by formula (9):

$$f\left(S_k^t\right)=F\left(S_k^t\right)-F_{\min}, \quad (9)$$

where F (S_k^t) is the value of the objective function of the k-th chromosome, where k = {1, 2,…, K}; F_{min} is the smallest value of the objective function [24].

The selection of parent chromosomes for crossbreeding is based on the value of the target function so that with non-zero probability any element of the population could be selected as one of the parents for crossbreeding.

In this method, the selection of chromosomes is carried out using a linear ranking. To do this, we first calculated the fitness of each individual f(S_k^t) by formula (9), then the population was sorted by increasing the fitness of individuals. Next, for each individual was calculated the value of P_{sl} (Pos) by formula (10):

$$P_{sl}(Pos)=2-SP+2\cdot(SP-1)\cdot\frac{Pos-1}{K-1}, \quad (10)$$

where Pos is the position of the chromosome in the population (the least adapted chromosomes have Pos = 1, and the most adapted have a position equal to K); SP is the selection pressure coefficient, which can take a value within [1; 2] [25].

During testing of the method, it was found that it is better to use SP = 1.6 and P_{sl} (Pos) = 0.58. If P_{sl} (Pos)> 0.58, then the chromosome is suitable for crossing.

To calculate the value of the target function for each PS placement option, you must first assign each consumer to the PS.

The method of fixing consumers for PS was created in the work, it takes into account two main factors: the amount of transmitted power and distance. The method of fixing consumers to the PS of the same size is to meet two conditions: the distance from the consumer to the selected PS - the shortest compared to other PS and the total capacity of consumers assigned to the selected PS does not exceed its capacity. If these two conditions are met, then the i-th consumer is assigned to the selected PS.

The crossbreeding operator, also called the crossover, is the main genetic operator that exchanges genetic material between individuals. Let's choose a variant of crossing in which two chromosomes are always involved to create a new daughter chromosome [26].

We will demonstrate the work of the crossing operator on the example of the problem, where it is necessary to place 6 PS to cover the total capacity of consumers from ten possible locations of PS.

First, we randomly select two different chromosomes from the created population.

The number of units in the first rows of both chromosomes should be the same and equal to the number of PS required to cover the total power of consumers.

The chromosomes then compare to see if they have the same genes, ie the same PS locations. As you can see from the Table-2 and Table-3, these are genes one, three, ten. These genes are passed on to the chromosomes of the offspring without change. Genetic information that is present in the chromosomes of both parents is much more likely to be passed on to offspring. We will assume that this information is transmitted with 100% probability. Next, we compress the selected chromosomes, rejecting the found identical genes and places in which there is no PS (value equal to zero).

The number of units in the first rows of both chromosomes should be the same and equal to the number of PS required to cover the total power of consumers.

The next step was to use a one-point crossover. The position of a gene (breakpoint) in a chromosome that divides both chromosomes into two parts is determined randomly. The chromosome of each parent consists of n genes, it is obvious that the point of intersection n_k is a natural number that is less than n [27]. Therefore, determining the breakpoint is reduced to random selection of a number from the interval [1, n - 1]. Suppose, for example, that it is a point between the first and second genes. As a result of crossing a pair of parental chromosomes, the following pair of offspring is obtained:

- A descendant whose chromosome at positions one to n_k consists of the genes of the first parent, and at positions $n_k + 1$ to n - the genes of the second parent [28].
- A descendant whose chromosome at positions one to n_k consists of the genes of the second parent, and at positions $n_k + 1$ to n - the genes of the first parent [29].

Thus, if the same genes of the parents are passed on to the offspring, the offspring inherit stronger genes, and chromosome compression greatly simplifies the operation of crossing [30].

The implementation of the mutation operation is a random change in the genotype of the daughter elements identified in the previous stage. The simplest mutation is to randomly alter one or more genes. In the genetic algorithm, mutation plays an important role in restoring genes dropped from a population during a selection operation so that they can be used in new populations. In addition, it allows the formation of genes that were not present in the original population [31]. In the developed method, one non-zero gene and one zero gene are randomly selected for each individual, after which their binary values are changed to the opposite. Let us demonstrate the implementation of the mutation operator on the example of chromosome D. Suppose that the second and seventh genes for the mutation are chosen at random.

Formation of a new generation. After crossing and mutation, it is necessary to create a new population. The types of operators of formation of the new generation (reproduction) practically coincide with the types of operators of selection of parents, which provide for the formation of an intermediate array of individuals admitted to crossbreeding [32].

It is necessary to determine which of the new individuals will enter the next generation and which will not. Among the most common selection operators, proportional selection was chosen, which is implemented by the method of roulette on the terms of ease of implementation and low computational costs due to the complex nature of the device function [33].

First, the arithmetic mean of the fitness function fam of the population of all K individuals was determined by formula (11) [34]:

$$f_{am} = \frac{1}{K}\sum_{k=1}^{K} f\left(S_k^t\right). \qquad (11)$$

Next, the calculation was performed for each individual the following ratio according to formula (12) [35]:

$$f_r\left(k\right) = \frac{f\left(S_k^t\right)}{f_{am}}. \qquad (12)$$

Individuals are selected using r roulette runs equal to the number of individuals in the initial population specified by the user. The roulette wheel contains one sector for each person in the population. The size of the r-th sector is proportional to the value of $f_r(k)$. An individual falls into a new population if a randomly generated number in the range from zero to 2π falls into the sector corresponding to that individual. In such selection, members of the population with higher adaptation are more likely to be selected than individuals with low adaptation [36].

The developed method stops its work at achievement of the maximum number of epochs of functioning which is set by the user.

Therefore, a modification of the method of placement of power supply facilities in the case of the same standard size of power sources is proposed. The developed method is based on the principles of evolutionary modeling and genetic programming. This method implements the placement of several PS of the same size and the simultaneous attachment of consumers to these PS. It allows for an even distribution of electrical power consumers between PS and reduce the distance from PS to consumers.

The second modification of GA is to implement the placement of PS of different sizes and the simultaneous attachment of consumers to them. We will demonstrate the structure of the developed method of placement of PS of different sizes on the example of the problem. Under the condition of the problem, the total power consumption is 23 MW and it is known that the typical series includes power supplies of the following capacities: 4 MW, 6 MW, 12 MW. Therefore, according to the given typical series $P_{sum.give}$ = 24 MW [6]. Input data are possible locations of PS, standard sizes of used PS, all possible options of power supply and $P_{sum.give}$. In this example, 6 possible options for power supply, and each option has its own required number of locations PS. Arrange the options in descending order of the required number of locations PS.

The principle of formation of the initial population. In this formulation of the problem in the initial population must be present all possible options for power supply from the set V = {1, 2,…, v}, and must be used all possible locations of PS from the set J = {1, 2, …, N}. Each chromosome will contain information about the combination of the number and size of PS used, as well as information about the location of PS for this variant of power supply.

Let J = {1, 2,…, n} be the set of possible PS locations, in our case it is equal to ten elements. The length of the chromosome is equal to the number n - the number of possible locations of PS. The number of chromosomes in the initial population should be equal to the number v. The chromosome consists of three lines: the value, the possible locations of the PS and the power of the PS. The value string is a bit string and the sum of the units in this string must be equal to the number of PS used in the selected power supply option. The sum of the numbers in the third line must be equal to the total power consumption. The location of the corresponding units in the first line and the numbers in the third line is chosen randomly.

Selection of chromosomes for crossing is carried out by means of uniform ranking. First, the fitness of each individual f (S_k^t) was calculated by formula (9), then the population was sorted by increasing the fitness of individuals. Next, for each individual was calculated the value of Psr (S_k^t) by formula (13):

$$P_{sr}\left(S_k^t\right)=\begin{cases}\frac{1}{w}, & 1\le k\le w\\ 0, & w<k\le K\end{cases}, \qquad (13)$$

where w is a number equal to | K / 2 | [37-38].

If P_{sr} (S_k^t) is not zero, then the chromosome is suitable for crossing.

To calculate the value of the target function for each PS placement option, you must first assign each consumer to the PS.

The method of fixing consumers for PS was created in the work, it takes into account two main factors: the amount of transmitted power and the distance from PS and the consumer. Let's move on to the description of the method of fixing consumers for PS of different sizes. First you need to organize the power (weight) of consumers in descending order $S_1 \ge S_2 \ge \ldots \ge S_m$. Also arrange the PS powers used for this solution in descending order $P_1 \ge P_2 \ge \ldots \ge P_t$. The method of fixing consumers for PS of different sizes is to meet two conditions: the distance from the consumer to the selected PS - the shortest compared to other PS and the total capacity of consumers assigned to the selected PS does not exceed its capacity. If these two conditions are met, then the i-th consumer is assigned to the selected PS.

In the method of placing PS of different sizes, a variant of crossing was chosen in which two chromosomes participate to create a new daughter chromosome [39]. Before proceeding with the operation of crossing, it was necessary to modify the chromosomes of the parents. To do this, the parents' chromosomes were first divided into the largest common power divider, and then a single-point crossover was used. After that, the obtained progeny chromosomes were analyzed and the power was redistributed by PS according to the specified size options to cover the power consumption.

The mutation operator is to change genes in randomly selected positions. It initiates diversity in the population, allowing you to view more points in the search space and thus overcome local extremes during the search [30]. The mutation occurs in this way, a number from the second line is randomly selected and replaced by a random number from the set J = {1, 2,…, n}, which is not equal to the numbers already in the second line.

We will carry out selection of genetic material by means of proportional selection which is realized by a roulette method. This type of selection has already been used and described for the method of placing PS of the same size. With such selection, members of the higher-fit population are more likely to be selected than low-fit individuals. As a result of the selection operation, the best chromosomes are selected to create a new population. The number of roulette runs is equal to the number of individuals in the initial population, so the new population will be the same size as the original created.

The developed method stops its work at achievement of the maximum number of epochs of functioning which is set by the user [38-44].

Therefore, a modification of the method of placement of power supply facilities in the case of different sizes of electric power sources is proposed. The developed method is based on the principles of evolutionary modeling and genetic programming. This method implements the placement of several PS of different sizes and the simultaneous attachment of consumers to these PS. It allows for an even distribution of electrical power consumers between PS and reduce the distance from PS to consumers.

THE RESULTS OF THE GENETIC METHOD OF PLACEMENT OF PS OF THE SAME AND DIFFERENT SIZES IN THE URBAN DISTRIBUTION NETWORK

We test the developed method with the following parameters: the number of individuals in the initial population Number of Chromosomes = 200 and the number of iterations of the method Number of Iterations = 200. In Figure-1 and in fig. 2 presents the results of the developed method.

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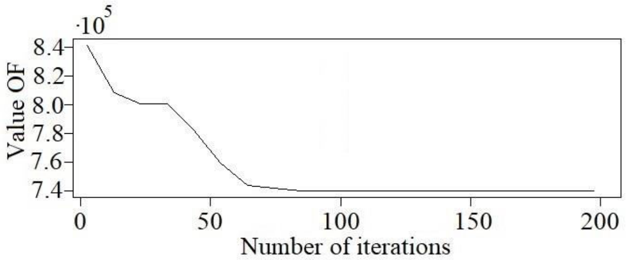

Figure-1. Graph of change of the objective function (Number of Chromosomes = 200, Number of Iterations = 200).

In fig. Figure-1 shows a graph of changes in the value of the objective function during the transition from one population to another and which clearly shows a gradual decrease in the value of the objective function. As can be seen from Figure-3.1 on average, starting from 90 populations, the value of the objective function stops decreasing and is $7{,}415 \cdot 10^5$ - this means that the method coincides and reaches the global minimum.

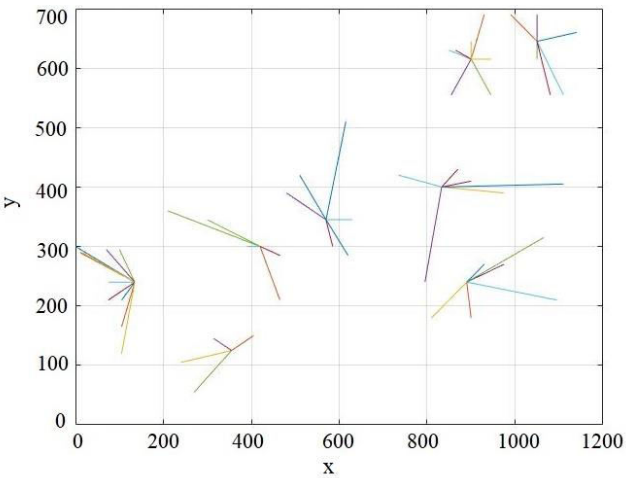

Figure-2. The schedule of fixing consumers for PS.

As can be seen from Figure-2 locations of PS, issued during the development of the developed method at a given source data: X_1 = 833, Y_1 = 400, X_2 = 420, Y_2 = 300, X_3 = 890, Y_3 = 240, X_4 = 240, Y_4 = 75, X_5 = 900, Y_5 = 615, X_6 = 1050, Y_6 = 645, X_7 = 135, Y_7 = 240, X_8 = 570, Y_8 = 345.

We will test the developed method by changing the parameters in the input data, namely by accepting Number Of Iterations = 100 and Number of Chromo = 250.

The graph of change of objective function at Number of Chromo = 250, Number of Povtoremi = 100 is presented in Figure-3.

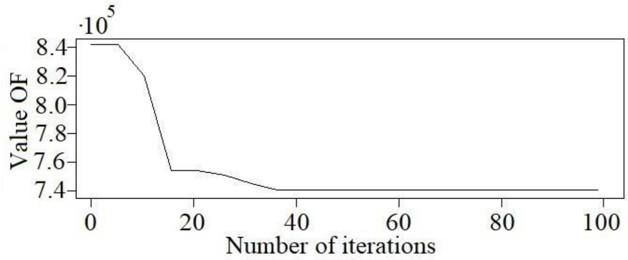

Figure-3. Graph of change of the objective function (Number of Chromosomes = 250, Number of Iterations = 100).

As can be seen from Fig. 3, there is a situation similar to the previous testing - a gradual decrease in the target function. Based on previous testing of the method, 100 populations were selected to test the developed method. At the end of testing, there is a convergence of the method and stop the decrease in the target function.

Fixation of consumers of electric power on PS, received as a result of work of a method at the set parameters is presented on Figure-4.

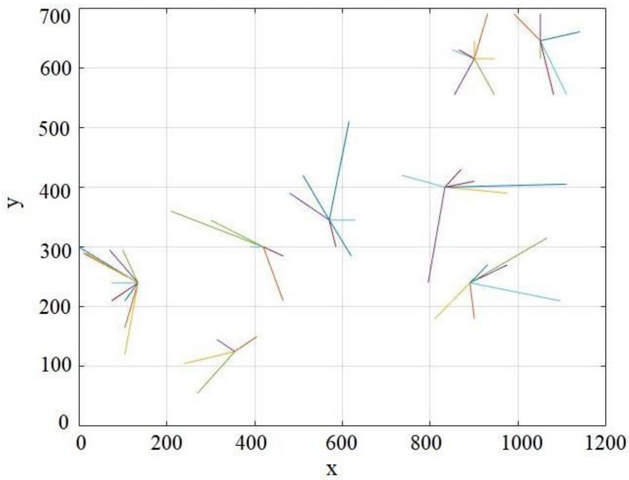

Figure-4. Schedule of consolidation of consumers for PS.

You can see that in Figure-4 shows the locations of the PS, issued during the development of the developed method at a given input data: X_1 = 833, Y_1 = 400, X_2 = 420, Y_2 = 300, X_3 = 890, Y_3 = 240, X_4 = 240, Y_4 = 75, X_5 = 900, Y_5 = 615, X_6 = 1050, Y_6 = 645, X_7 = 135, Y_7 = 240, X_8 = 570, Y_8 = 345.

Let's analyze the work of the method with the following parameters: Number of Chromo = 400, Number of Povtorenii = 100, ie increase the number of individuals in the population several times. We obtain the results presented in Figure-5 and in Figure-6.

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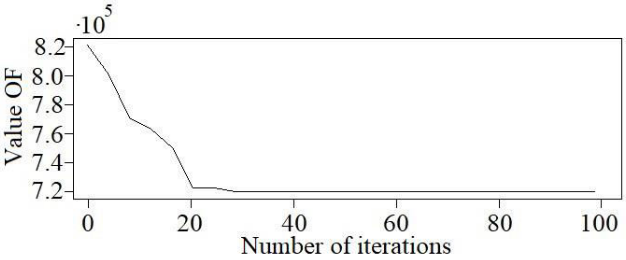

Figure-5. Graph of change of the target function from the population (Number of Chromosomes = 400, Number of Iterations = 100).

In Figure-5 shows a graph of the change in the value of the objective function during the transition from one population to another and which shows a gradual decrease in the value of the objective function. Starting with 30 populations, there is no further decrease in the value of the objective function, which is $7.22 \cdot 10^5$, so we can assume that during testing the global minimum value of the objective function was reached. Comparing the results presented in Figure-1 and in Figure-3 it can be seen that the convergence of the method increases with increasing number of individuals in the initial population. During testing, it was found that the search for the best solution in which the value of the objective function is the lowest depends on the selected number of individuals in the population. The larger the population, the better the chances of finding the best option for placing PS and securing consumers for them.

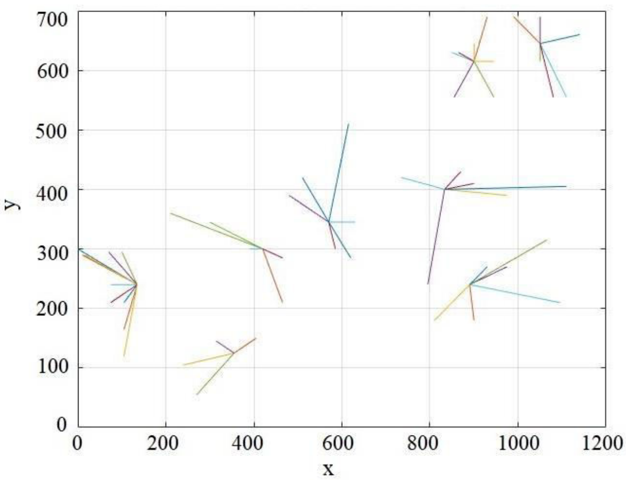

Figure-6. Schedule of consolidation of consumers for PS.

In Figure-6 shows the location of the PS, issued during the operation of the genetic method at a given input data: $X_1 = 833$, $Y_1 = 400$, $X_2 = 420$, $Y_2 = 300$, $X_3 = 890$, $Y_3 = 240$, $X_4 = 355$, $Y_4 = 125$, $X_5 = 900$, $Y_5 = 615$, $X_6 = 1050$, $Y_6 = 645$, $X_7 = 135$, $Y_7 = 240$, $X_8 = 570$, $Y_8 = 345$.

We will conduct a comparative analysis of the results of the method of placing PS of the same size and simultaneous fixation of consumers with different numbers of iterations and chromosomes in the initial.

As can be seen from table. 1 initially tested the developed method with an initial population of 200 individuals and the number of iterations in this experiment is 200 times. On the basis of which the value of the objective function was obtained, which is equal to $7{,}415 \cdot 10^5$ and the execution time of the method, which is 96,063s. Then the number of iterations was reduced to 100 times and the number of individuals in the initial population was increased to 250 individuals. As a result, the value of the objective function was obtained, which is equal to $7{,}413 \cdot 10^5$ and the execution time is 96,153s. Thus, comparing these two experiments, we can see that the values of the objective function and the calculation time have not changed much. In the third experiment, the initial population was increased to 400 individuals and the number of iterations of the algorithm was left unchanged. Then it was obtained to reduce the objective function to $7, 22 \cdot 10^5$ and increase the calculation time to 153,201s. Thus, the results of the analysis show that the time of the method increases with increasing number of chromosomes in the initial population and decreases the value of the target function. The dependence of the time of the method on the number of iterations with a constant number of chromosomes in the initial population is much weaker. The results of these three experiments show that the time to find a solution to the method depends more on the number of chromosomes in the initial population, and to a lesser extent on the number of iterations of the method. This difference is due to the fact that the length of chromosomes is determined by the number of possible locations of PS, which are present in the task. That the time of the method increases with increasing number of chromosomes in the initial population and decreases the value of the target function. The dependence of the time of the method on the number of iterations with a constant number of chromosomes in the initial population is much weaker. The results of these three experiments show that the time to find a solution to the method depends more on the number of chromosomes in the initial population, and to a lesser extent on the number of iterations of the method. This difference is due to the fact that the length of chromosomes is determined by the number of possible locations of PS, which are present in the task. That the time of the method increases with increasing number of chromosomes in the initial population and decreases the value of the target function. The dependence of the time of the method on the number of iterations with a constant number of chromosomes in the initial population is much weaker. The results of these three experiments show that the time to find a solution to the method depends more on the number of chromosomes in the initial population, and to a lesser extent on the number of iterations of the method. This difference is due to the fact that the length of chromosomes is determined by the number of possible locations of PS, which are present in the task. That the time to find a solution to the method depends more on the number of chromosomes in the initial population, and to a lesser extent on the number of iterations of the method. This difference is due to the fact that the length of chromosomes is determined by the number of possible locations of PS, which are present in the task. that the time to find a solution to the method depends more on the number of chromosomes in the initial population, and to a lesser extent on the number of iterations of the method. This difference is due to the fact that the length of chromosomes is determined by the number of possible locations of PS, which are present in the task.

Table-1. Comparative analysis of the modes of operation of the method of placement of PS of the same size.

The number of chromosomes in the initial population	**200**	**250**	**400**
Number of iterations	200	100	100
The value of OF.	$7{,}415 \cdot 10^5$	$7{,}413 \cdot 10^5$	$7.22 \cdot 10^5$
Time, s	96,063 th most common	96,153 th most common	153,201

The most important question is how well-designed the method is to solve the problem. For this purpose, a comparative analysis of the results of the developed method with such methods as classical GA, full search algorithm, branch and boundary method, ant colony method was performed. The evaluation criteria were the values of the target function and execution time (Table-2).

Table-2. Comparative analysis of the results of the developed method of placement of PS of the same standard sizes

Criteria	**Developed method**	**Classic GA**	**Complete search algorithm**	**The method of branches and boundaries**	**The method of ant colonies**
The value of OF.	$7{,}223 \cdot 10^5$	$12{,}234 \cdot 10^5$	$6{,}534 \cdot 10^5$	$6{,}912 \cdot 10^5$	$6{,}925 \cdot 10^5$
Time, s	153,201	123,156 th most common	17204,466	16928,546	16582,523

You can see from the Table-2, that the developed method has a gain in time of calculation in comparison with exact methods. For example, the calculation time of the full search algorithm is 17240,466 s, which is much longer than in the developed modification, in which the calculation time is equal to 153,201 s. It is also observed that the values of the objective function of the method of placement of PS of the same standard sizes are close to the values of the objective function of exact methods. For example, the value of the objective function in the method of branches and boundaries is equal to $6{,}912 \cdot 10^5$, and in the proposed method is $7{,}223 \cdot 10^5$. Comparing the developed modification and the classic GA, we can see that the developed method shows the best values of the objective function, but it uses more time resources. Because, crossbreeding and mutation operators with a probability of 100% are applied to all individuals of the generation in turn, in contrast to the classical GA. In addition, in small-dimensional problems, the developed method of placing PS of the same standard size receives solutions that are very close to accurate.

We demonstrate the work of the developed method of placing PS of different sizes on the example of the problem [18], where you need to choose the most economical option for placement of PS. In the condition of the problem it is known that $P_{sum.con} = 3300$, $P_{sum.give} = 3450$, the typical range includes PS of the following powers: 50 kW, 100 kW, 500 kW, 1150 kW, and also known variants of combinations of quantity and standard sizes: $1150 \cdot 2 + 500 \cdot 2 + 100 \cdot 1 + 50 \cdot 1 = 3450$, $1150 \cdot 3 = 3450$, $500 \cdot 4 + 100 \cdot 3 + 1150 \cdot 1 = 3450$ [18]. The input data will also be the coordinates of possible locations of the PS and the coordinates of electricity consumers [18].

Let's start work of a method, having specified Number of Povtorenii = 100. Thus we receive the following results presented in Figure-7 and Figure-8.

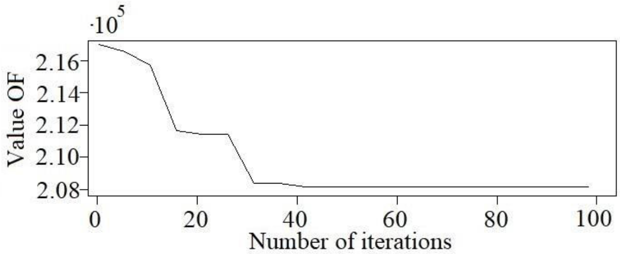

Figure-7. Target change graph (Number of Iterations = 100).

In fig. Figure-7 shows a graph of the change in the value of the objective function during the transition from one population to another and which clearly shows a gradual decrease in the value of the objective function. As can be seen from Figures 3.7 on average, starting from 45 populations, the value of the objective function stops decreasing and is 2.08 · 105, which means that the method coincides and reaches the global minimum.

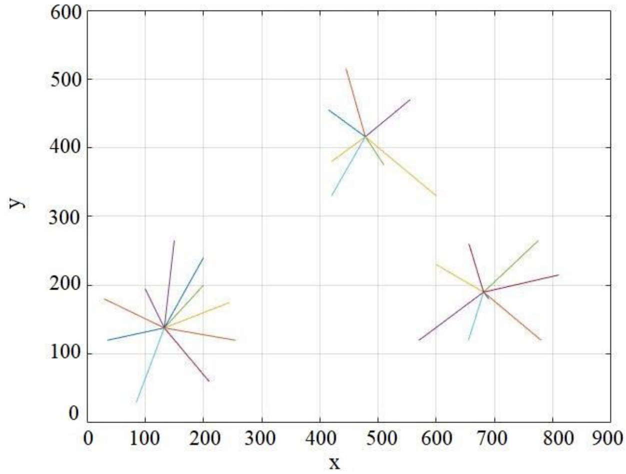

Figure-8. Schedule of consolidation of consumers for PS.

As can be seen from Fig. 8 locations of PS, issued during the operation of the method at a given input data: X_1 = 130, Y_1 = 138, X_2 = 479, Y_2 = 417, X_3 = 681, Y_3 = 191, corresponding to the third variant of the combination of the number and size of PS. Therefore, the best solution is to place three PS in the resulting places with a capacity of 1150 kW.

The comparative analysis of results of the developed method with such methods as, classical GA, algorithm of full search, a method of branches and borders, a method of ant colonies is carried out. The evaluation criteria were the values of the target function and execution time (Table-3).

Table-3. Comparative analysis of the results of the developed method of placement of PS of different sizes

Criteria	Developed method	Classic GA	Complete search algorithm	The method of branches and boundaries	The method of ant colonies
The value of OF.	$2{,}081 \cdot 10^5$	$4{,}110 \cdot 10^5$	$1{,}836 \cdot 10^5$	$1{,}976 \cdot 10^5$	$1{,}921 \cdot 10^5$
Time, s	204,265 th most common	163,924	19055,562	18564,431	18621,233

You can see from the Table-3, that the developed method has a gain in time of calculation in comparison with exact methods. For example, the calculation time of the ant colony method algorithm is 10,233 s, which is much longer than in the developed modification, in which the calculation time is equal to 4,265 s. It is also observed that the values of the objective function of the method of placement of PS of different sizes are close to the values of the objective function of exact methods. For example, the value of the objective function in the full search algorithm is equal to $2{,}110 \cdot 10^5$, and the proposed method is $2{,}081 \cdot 10^5$. Comparing the developed modification and the classic GA, we can see that the developed method shows the best values of the objective function, but it uses more time. Because, crossbreeding and mutation operators with a probability of 100% are applied to all individuals of the generation in turn, in contrast to the classical GA. In addition, in small-dimensional problems, the developed method of placing PS of different sizes receives solutions that are very close to accurate.

DISCUSSION OF THE RESULTS OF THE DEVELOPMENT OF A GENETIC METHOD FOR PLACING POWER SUPPLIES OF THE SAME AND DIFFERENT SIZES

Analyzing the obtained experimental results (Table 2), we can see that in contrast to the exact methods for small and medium-sized problems, the calculation time using the developed method is much shorter. This can be seen by comparing, for example, the method of complete search, in which the calculation time is 17240,466s and the created method of placing PS of the same size, in which the search time of the solution is 153,201s. Thus, the experimental data in Table-5 indicate that the created method of placement of PS of the same standard sizes works on10.3%faster than accurate methods. Also from

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test calculations in Table-2 shows that the average error of the value of the objective function determined by the proposed method does not exceed the value of 0.064 relative to the value of the objective function set by the exact methods. In the table 1 presents a comparative analysis of the created method and the classical GA, which showed that the developed method shows much better values of the objective function, but it uses more time resources.

The calculation time and the value of the objective function were estimated depending on the specified parameters of the method of placement of PS of the same size. As a result, it was found that the search for the best solution depends more on the size of the initial population and to a lesser extent on the number of iterations. As can be seen from Figure-3 with a reduced number of iterations, the process of convergence to a single solution is slower. In the course of numerous experiments, a smooth convergence of the solution to the result was noted, which is shown in Figure-3, with increasing size of the initial population. Shifting this parameter of the method setting upwards increases the quality of the obtained solution, but at the same time increases the cost of machine time required to obtain the result, as shown in Table-2. The above results allow us to conclude that that with the increase in the number of individuals the accuracy of the genetic algorithm improves, but the calculation time increases. Based on the obtained data, it follows that the highest quality of PS placement is achieved with the largest possible population size. However, there is a significant disadvantage, namely - the running time of the algorithm, as the computational complexity of GA directly depends on the number of individuals. With a population size of 1,500 individuals, the best result is achieved, but the running time of the algorithm does not justify this improvement, so the recommended population size is 1,000 individuals. Since the computational complexity of GA directly depends on the number of individuals. With a population size of 1,500 individuals, the best result is achieved, but the running time of the algorithm does not justify this improvement, so the recommended population size is 1,000 individuals. Since the computational complexity of GA directly depends on the number of individuals. With a population size of 1,500 individuals, the best result is achieved, but the running time of the algorithm does not justify this improvement, so the recommended population size is 1,000 individuals.

Analyzing the results of experiments (Table-3), we can see the speed of finding a solution to the developed method of placing PS of different sizes in comparison with the exact methods on average on 9.8%higher. Also, the analysis of the obtained test calculations shows that the modified GA gives a solution close to the solution obtained by the method of complete search or equal to it. From the table. 3 it can be seen that the average error of the value of the objective function determined by the proposed method does not exceed the value of 0.094 relative to the value of the objective function set by the exact methods.

The study of the dependence of the selected parameters of the method and the obtained results was carried out and the recommended parameters with which the genetic method of placement of PS of different sizes will show the best results were established. The recommended number of generations is 70. In most cases, after the 70th generation there was no change in the target function (Figure-7).

Thus, summarizing the above, we can say that the developed methods of placement of PS of the same and different sizes allow to solve the problem of optimizing the finding of a globally optimal solution in a reasonable time. This is achieved through proposed specific genetic operators of crossing and selection, which effectively solve the problem of low inheritance, topological impracticability of the solutions found, resulting in significantly reduced execution time and increased accuracy of calculations.

CONCLUSIONS

A genetic method has been developed to solve the problem of optimal placement of PS of the same size and at the same time assigning consumers to them. The fundamental difference between the proposed method and existing analogues is the use of a modified selection operator, which selects chromosomes from the population by predicting the quality of the offspring that can give the selected chromosomes. To do this, the selection operator takes into account the scheme of the operator of the crossing over and mutation. The use of the developed selection operator allows to exclude the occurrence of solutions that do not meet the condition of the problem and thus improve the quality of the obtained solutions. During testing of this method it was found that the speed of finding a solution compared to the method of complete search is higher by 12.3%, branches and borders by 10.5%, ant colonies by 8.2%.Also, the analysis of the obtained test calculations shows that the modified GA gives a solution close to the solution obtained by the method of complete search or equal to it. The average error of the value of the objective function determined by the proposed method does not exceed the value of 0.105 in relation to the value of the objective function set by the method of complete search.

A genetic method has been developed to solve the problem of optimal placement of PS of different sizes and at the same time assigning consumers to them. The main difference between the developed genetic methods of placement of PS of different sizes from known genetic algorithms is the use of a modified crossover operator, in which after determining the break point is the redistribution of genes. That is, the proposed crossover operator redistributes electricity between power sources to maintain a balance between total power consumption and total power output to the network by the power source. Also, the fundamental difference between the proposed methods from existing analogues is the use of a common mutation operator for the location and power output of the power supply. In this situation, the power of the PS will change completely, because a change in its location automatically entails a change in the power produced 9.89% less. Also, the analysis of the obtained test calculations shows that the modified GA gives a solution close to the solution obtained by exact methods. For example, the value of the objective function in the full search algorithm is equal to $1.836 \cdot 10^5$, and the proposed method is 2.081 · 105.

An experimental study of the proposed genetic methods of placement of PS of the same and different sizes was performed. The results of research have shown that created a method of placing PS of the same size works on 10.3% faster than accurate methods. Also from test calculations it is seen that the average error of the value of the objective function determined by the proposed method does not exceed the value of 0.064 in relation to the value of the objective function established by exact methods. Also during the study, a comparative analysis of the created method and the classical GA was performed, which showed that the developed method shows much better values of the objective function, but it uses more time resources. The value of the objective function in the classical GA is $12, 234 \cdot 10^5$ and the calculation time is 123,156, and in the proposed method the value of the objective function is $7{,}223 \cdot 10^5$ and the calculation time is 153,201. The research results showed that the speed of finding a solution to the developed method of placing PS of different sizes in comparison with the exact methods on average by 9.8% higher. Also, the analysis of the obtained test calculations shows that the modified GA gives a solution close to the solution obtained by exact methods. It is established that the error of the value of the objective function determined by the proposed method does not exceed the value of 0.094 in relation to the value of the objective function determined by the exact methods.

ACKNOWLEDGEMENT

The work was performed within the research topic "Methods and tools for decision making for data processing in intelligent image recognition systems" (№ state registration 0117U003920) of the Department of Software Zaporizhia National Technical University.

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