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Classifier System and Co-evolutionary Hybrid Approach to Restoration Service of Electric Power Distribution Networks

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Abstract – The method proposed by the author is intended for assistance in decision-making (concerning changes of connections) by operators of complex distribution systems during states of malfunction (particularly in the events of malfunctions, for which the consequences encompass extended parts of the network), through designation of connection action scenarios (creating substitute configurations). It is the use by the classifying system working with the co-evolution algorithm that enables the effective creation of substitute scenarios for the Medium Voltage electric power distribution network. The author also completed works concerning the possibility of using cooperation of the evolutionary algorithm and the co-evolutionary algorithm with local search algorithms. 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.

Keywords: Co-evolutionary algorithms, Hybrid algorithm, Classifier systems, Distribution power networks, Restoration service

1. Introduction

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 [1-3]. This problem has been approached using heuristics [4, 5], mathematical programming [6, 7]. Heuristic search algorithms - their use is hindered in the event of calculations for large numbers of current network nodes in the analysed network. In such instances assumptions may be applied limiting the extent of solutions, which reduces the calculation process, but in consequence causes the search for sub-optimal solutions.

Genetic and evolutionary algorithms - the benefit of application of evolutionary algorithms is the possibility of their use in large numbers of decisively variable decisions and also complex descriptions of function purpose and limiting conditions. These algorithms with known network structure and parameters and also known loadings of particular network nodes, enable the designation of activity scenarios of connections restoring network operation. In works [7, 8, 10] are presented methods concerning the use revolution algorithms drawn up to resolve multi-criteria problems in optimising electric power networks. These methods concern the development of specialised means of coding, reproduction methods based on domination and also use of co-evolutionary approaches. Several evolutionary algorithms have been developed to deal with distribution system reconfiguration problems. Although the obtained results have been encouraging, the majority of evolutionary algorithms still demand high running time when applied to large-scale distribution systems [7, 8].

The analysed problem of choosing the substitute configuration of the distribution system can be described as a multiobjective programming problem. In the article the author presented the results of his works concerning the method drawn up using the system classifying cooperation with the co-evolutionary algorithm, in order to assist the work of electrical energy distribution systems operators.

The elaborated method uses the classifying system to determine, for the assumed conditions, the most profitable distribution network configuration. The important feature of the method is the possibility to form the substitute network configuration with the use of information coming from the simulated network operation states, where the information on reliability parameters of the network or exploitation periods of the network elements can be also exploited. The author also completed works concerning the possibility of using cooperation of the evolutionary algorithm and the co-evolutionary algorithm with local search algorithms.

The application of hybrid algorithms (in the solution of various optimisation problems) enables achievement of better results than those achieved by the separate application of the methods referred to, this conclusion is borne out by the results of research. The conclusion of the work of the author is the proposed application of a hybrid approach combining the positive traits of the previously named algorithms to search for optimal post-malfunction

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network configurations. Such an approach according to the results of the research conducted by the author enables increased effectiveness in the designation of substitute network configurations especially in the case of a network with a very large number of elements.

2. Theoretical part

The classifier system is a system that learns the syntactic simple rules in order to co-ordinate its actions in any environment and includes the three basic components [9]: rule and message system, evaluating system and evolutionary algorithm.

In the classifier system the information from the outer environment is processed into the messages of a given format. The messages are further placed on the message list, where they can activate the classifiers. The classifier is an attribution rule of the following syntax:

<classifier> : : = <condition> : <message>

The elaborated method is characterised by the possibility of gathering the information on the occurred and simulated network fault states. The information can be further used in creation of the new network configuration variants for the fault operation conditions. Such information can be also used creation and modification of the classifier set that is the main rules set. In the genetic machine learning systems theory appropriate ways enabling to keep the efficient classifiers and to remove the inefficient ones are known.

2.1 Rule and message system

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In the elaborated method (based on the classifier system idea) known procedures, performing message processing or classifier evaluation have been used. Certain modifications resulting from the specificity of the considered problem, have been introduced:

- the message about the fault is described in the form: a list with numbers of not supplied nodes, and a list with numbers of fault elements :
  <message>:: =(numbers of not supplied nodes)+ (numbers of fault elements)
- in the classifier notation following syntax has been taken into account in the notation actually used:
  <classifier>::= <condition>:<message>
  <classifier>::=< numbers of not supplied nodes + numbers of fault elements>:<post-fault configuration>

With regard to the specific character of the analysed task (concerning breakdown of elements in the network structure) the author has drawn up a modified announcement processing procedure (describing network break down situations). In the suggested method the announcement processing process and the evaluation of classifiers is divided into two stages described below.

Stage 1 consists of the search in the collections of classifiers for such, for which the conditions are compatible with the announcement describing the existing network breakdown. Comparison of the announcement (containing information about damaged network elements and of network nodes deprived of current supply) with the conditions of classifiers enables the search and activation of classifiers containing coded information about network configurations, in which there are no damaged elements. Conformity of the announcement with the conditions of the classifiers in the first stage of the suggested method is defined on the basis of comparison of the numbers of network nodes without power supply recorded in the announcement, with the numbers of network nodes recorded in the first part of the classifiers (which corresponded to the concealed zeros on the appropriate positions of communication code tracts and classifier). After searching for classifiers conforming to the announcement the evaluation takes place of the so-called offer of these classifiers. The classifier distinguished by the highest offer was next used as a following announcement.

Stage 2 concerns the search for classifiers whose conditions will be according to the announcement of the classifiers designated in stage 1. The conformity of the announcement with the conditions of the classifiers in this stage was defined on the basis of the differences between the power supply routes of the chosen line sections (from the list of network nodes deprived of power supply) with the configuration recorded in the announcement and classifiers.

With regard for these specific nature of the analysed task the author suggested a two-part description of the announcement (describing the breakdown situation of the network). The first part of the announcement is recorded as a length of zero-ones relating to the number of elements equal to the number of network line sections of the analysed network. Value 1 on the defined position corresponding to the number of the network length, indicates length with power supply, and 0 indicates network node without power supply as a result of breakdown. The second part of the announcement contains information about the damaged elements and also information about the configuration of network elements. For the description of this part of the announcement the author introduced the following marking notation:

- 0 - means damaged element,
- 1 - means actually used element,
- # - means element remaining in reserve.

Below is showing an example of the process of creating announcements for the breakdown status of the electric power network system (composed of a small number of elements), the structure of which is reflected in graphic form on drawing 1. For the network graph from drawing 1, the case is examined of a breakdown on line l4. The announcement describing the considered breakdown status was described as follows:

message 1
111101000110111 | 11#0#####1#11####11##1
The sought for classifiers in the first stage (Fig. 2):
classifier 1
111101100110111 | 11110###11#1111##11##1
classifier 2
111101111111111 | 11111#01#1#11#1##11##1

After the performance of the first stage, the classifier characterised with the best assessment is used as the following announcement enabling continuation of the process of searching the collection of classifiers.

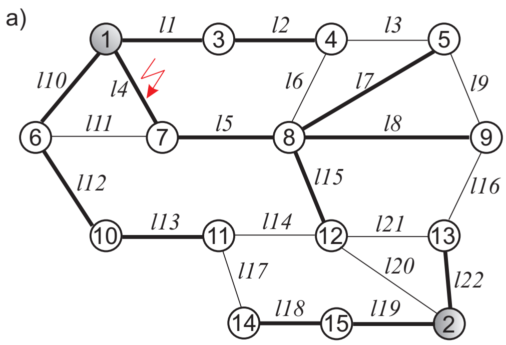

Fig. 1. Graph of the analysed distribution network

2.2 Evaluating system

In the initial part of calculations a message on the fault occurring in the network is being read. Procedures verifying the matching between the classifiers and the generated message are performed subsequently and then the classifiers are assessed. The strength S of the classifier, which has shown the best bid in the so-called auction process, is increased by the reward given by the system. Simultaneously its strength is decreased by the value of the bid given by the classifier [9].

$$S_i(t+1) = S_i(t) - c_{bid} \cdot S_i(t) - c_{tax} \cdot S_i(t) + r(t) \quad (1)$$

where: S_i – strength of the i-th classifier, c_{bid} – investment coefficient (c_{bid}=0,1), c_{tax} - turnover tax coefficient c_{tax}=001

The bid of the best classifier increases the strength of other active classifiers proportionally to their bids. Moreover, the strength of all the active classifiers is decreased by a certain, determined value. The effective bid value has been calculated in a following way [9]:

$$B_i = c_{bid} \cdot (e_{bid1} + e_{bid2} \cdot Sp_i) \cdot S_i \quad (2)$$

$$EB_i = c_{bid} \cdot (e_{bid1} + e_{bid2} \cdot Sp_i) \cdot S_i + e_{br} \quad (3)$$

where: B_i - bid value of the i-th classifier, EB_i - effective bid value of the i-th classifier, Sp_i - specificity of the i-th classifier, e_{bid1}, e_{bid2} – coefficients of the classifier linear specificity function (e_{bid1}=0,65, e_{bid2}=0,35), e_{br} – random value generated with the use of a normal distribution generator, r - coefficient of reward paid for the best classifier r=2.

The rule and message procedures perform the process of classifiers checking and evaluation, in aspect of using the information contained in them for solving the problematic situations. This allows for appointing of the group of classifiers containing the useful information on the searched post-fault network configuration.

2.3 Evolutionary algorithm

To modifications of the evolutionary algorithm enabling solutions of multi-criteria tasks are counted among others the application of the co-evolutionary approach. Application of the co-evolutionary algorithm to the analysed task creates m population; in each of them the adaptation function is defined on the basis of another component quality indicator vector. After successive performance (population supplementation with new elements), and through renewed reproduction, these populations are connected, and then were again divided so that each population elements may attain an unlimited population. The sought-after solution is the Pareto-optimal collection of solutions.

To encode the individuals representing various network configuration variants in a form of a sparse graph, the bequest of chromosomes in the form of a vector of inversion has been assumed. Each component of the vector of inversion, corresponding to the number of the graph node, is equal to the number of the supplying node.

A well-known roulette selection method on the remaining fractional part has been used as a selection method. A linear scaling method of population individuals' fitness function has been also used in the algorithm. Two specialised reconfiguration operators (crossover probability p_k=0,95, mutation probability p_m=0,15) have been used in the algorithm to create new solutions (its detailed description is contained in [10]). The aim of using of this kind of operator, 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 order to obtain proper solutions following limiting constraints resulting from technical requirements for proper operation of the distribution network have been taken into account:

- not exceeding of the maximum transmission currents of the line sections,
- not exceeding of the allowable voltage drops in the network nodes supply routes.

On the base of the source data [8-11] and own research following values of significant parameters of the calculation system have been assumed in the calculation procedures: number of classifiers *n=200*, crowding factor for classifier population $c_s=3$.

Following criteria have been assumed substantial for the optimisation problem of post-fault network configuration (of membership functions $f_1(X)$, $f_2(X)$, $f_3(X)$, $f_4(X)$, $f_5(X)$ used for main variables description):

- minimisation of the number of switching activities leading to obtaining a substitute network configuration:

$$f_1(X_j) = \min(n_j - n_0) \tag{4}$$

where $j = 1, 2, \ldots, m$
where: X_j – vector containing information on the *j-th* variant of the distribution network configuration, m – number of solution variants, n_j – number of switching activities, n_0 - number of switching activities in the basic configuration.

- minimisation of the undelivered power value:

$$f_2(X_j) = \min(\sum_{i=1}^{lw} P_{sr,i} \cdot q_i \cdot T_{p,i}) \tag{5}$$

where: $P_{sr,i}$ - average active load of the *i-th* user node of the network, l_w – number of nodes, q_i - unreliability factor of the supply circuit of the *i-th* user node, $T_{p,i}$ – operation time.

- minimisation of the voltage deviation in the network nodes:

$$f_3(X_j) = \min\{\max_i (U_i / U_N \cdot 100)\} \tag{6}$$

where: U_N – distribution network nominal voltage, U_i – voltage value in the *i-th* user node of the network,

- minimisation of the power load degree coefficient of the found group of the most loaded network elements:

$$f_4(X_j) = \min\{\max_k ((\sum_{i=1}^{n} P_{max,i})/n)\} \tag{7}$$

where: k - the number of power supply route network nodes of the reception network, n - the number of the most heavily loaded network elements.

- minimisation of the technical losses in the distribution systems:

$$f_5(X_j) = \min(\sum_{j=1}^{m} \frac{P_j^2 + Q_j^2}{U_N^2} \cdot R_j) \tag{8}$$

where: $f_5(X)$ – values of this function determine the technical losses value for the given variant of network configuration, m – number of sections being loaded in the given variant of network configuration.

The assumed membership functions used for the main variables description have been defined as follows:

$$u_i(X) = \begin{cases} 1, & \text{if} \quad f_i(X) \le f_i^{min} \\ \left(\dfrac{f_i^{max} - f_i(X)}{f_i^{max} - f_i^{min}} \right), & \text{if} \quad f_i^{min} < f_i(X) \le f_i^{max} \\ 0, & \text{if} \quad f_i^{max} < f_i(X) \end{cases} \tag{9}$$

The author applied cooperation of the co-evolutionary algorithm with the local search algorithm, which in this instance was the cycles and penalties algorithm. The cycles and penalties algorithm method is applied in the optimisation of dispersing power flows in electric power networks. Its main task is the minimising of technical losses through the optimisation of network configurations for the given network loading. For the purpose of applying this method to the designation of optimal post-malfunction network configurations the author introduced two modifications, consisting of limitation of the process implemented with its assistance to the area affected by the malfunction consequences. The introduction of this adaptation action did not change the principal assumptions of this method.

The first modification introduced regard in the formation stage of the list of reserved elements (on the basis of which so-called successive network cycles are created and considered) only for those network arcs, which form cycles containing network nodes deprived of power supply as a result of malfunction. The second modification concerns the use as a criteria function, (in the classic form the technical losses arising from the considered network cycle are calculated) of dependencies 4÷8.

The proposed hybrid algorithm is typified by the characteristic that in the first calculation stage it is used as the previously described evolutionary algorithm, which searches the collection of points in seeking the solution area, representing promising regions of this area. In the second part of the calculation process however the local search convergent algorithm is used, which using the previously designated points (in the form of alternative network configurations) designates the collection of best possible substitute network configurations capable of application (for the existing work conditions of that network). The collection of points represents promising regions of the area of permissible solutions obtained by the registration of 15 % of solutions contained in populations after performance of the specified number of iterations. Through this the number of performed iterations resulted from the testing of value changes of the best-obtained solutions in successive iterations. The calculation process with the participation of the evolutionary algorithm was interrupted after confirmation of lack of improvement in application of the best solutions in 40 successively executed iterations. The population from which was chosen the 15 % best solutions (as a collection of start points for the local search algorithm) was the population after the performance of the iteration, in which the final improvement was observed in application values of the best solution during the performance of the first stage of calculations. The proposed hybrid algorithm may also be used as a method based on cooperation of how evolutionary algorithm with the classifier system.

In multi-criteria optimization tasks including a set of different criteria (sometimes mutually exclusive), a solution being an optimum compromise between the assumed criteria is sought. A solution to a multi-criteria task is a set of non-dominated points, i.e. a set of Pareto-optimal solutions. In literature on the application of evolutionary algorithms to solve multi-criteria tasks, the assumed objective is to find the highest possible number of non-dominated solutions. The author has applied an algorithm with the coevolutionary approach facilitating the inclusion of the multi-criteria character of a task to the optimization task related to post-failure grid configurations. The aim of this approach is to find the highest possible number of Pareto-optimal solutions evenly covering the acceptable set of solutions in order to give the deciding party the fullest information and freedom of choice possible. The proposed algorithm with the coevolutionary approach has subsequently been applied as an element of the learning classifier system.

With the application of the coevolutionary approach, the algorithm processes several populations, and the fitness function is determined in each of them on the basis of a different constituent of the vector quality index. After succession (supplementing a population with new elements) and before another reproduction, information exchange between subpopulations takes place. In the proposed version of the algorithm the author, following calculations related to a given iteration, has merged the populations into one big population and assigned the elements to individual subpopulations at random. The proposed coevolutionary approach allows to obtain a set of the most favorable compromising solutions possible (according to the principle applied to the optimization in the Pareto sense).

3. Calculation example

In this part of the study the problem of calculation connected with the medium voltage urban electric power distribution network malfunction state is considered, the simplified electrical diagram and the graph of the analysed network are presented in drawings 2 and 3. The considered network malfunction state, which caused disconnection from normal operation of a section of bus-bars of the main station supplying number 6, the location of malfunction occurrence is marked on drawings 2 and 3. The consequence of this malfunction is lack of power supply for a significant proportion of the network nodes. The current of each branch is evaluated by deriving the distribution power flow equations for a radial configuration network.

The sought after solution is the designated substitute network configuration enabling restoration power supplies for the greatest number of consumer network nodes possible. The examined assignment is a multi-criteria optimisation task, for its solution the author proposed use of a co-evolutionary algorithm (as an effective method enabling the solution of this type of problem) working together with the classification system. The sought after solution of the analysed multi-criteria optimisation problem is the collection of Pareto-optimal solutions. In order to seek the distribution network substitute configurations enabling the most rational use of the existing network infrastructure the author considered the collection of five criteria described by dependencies 6÷11. Presented below is the announcement record describing the existing malfunction.

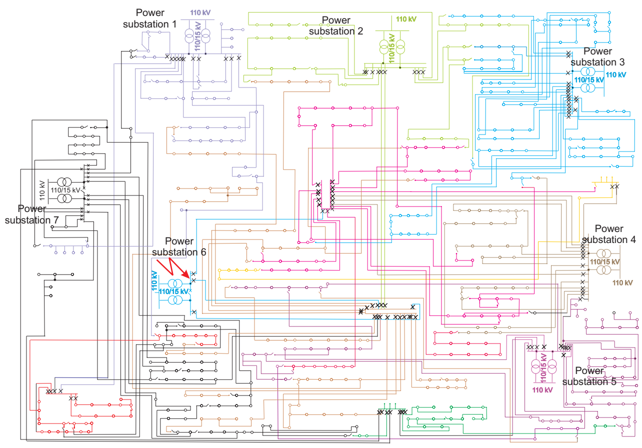

Fig. 2. Diagram of the analysed system

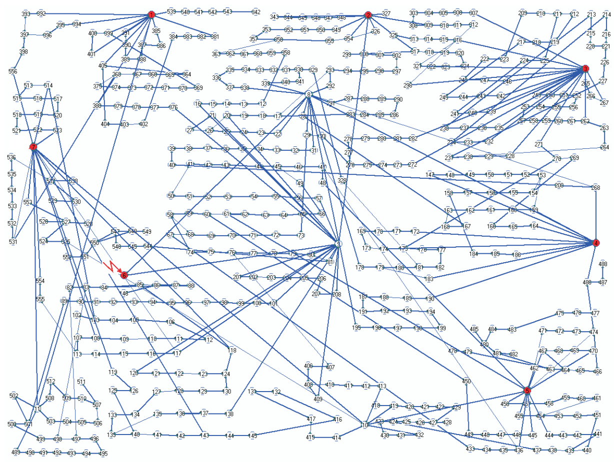

Fig. 3. Graph of the analysed medium voltage network

For the below considered breakdown situation in the analysed network, which is composed of 556 network nodes the author accepted the abbreviated description of announcements and also classifiers. The abbreviated description however contains instead of the zero-one tract (part of the first announcement) the numbers of line sections deprived of power, whereas as part of the second announcement the numbers of damaged elements are given. In the elaborated calculation model a so-called vector of inversion has been used for the network configuration description. Accepting such an abbreviated method of description for breakdowns existing in the analysed network, the announcement describing the breakdown is defined as follows:

<message>:: =(numbers of not supplied nodes)+ (numbers of fault elements)

The solution search process is performed by the method (based on the cooperation of the co-evolutionary algorithm and the classification system) as described in previous points. The significant assumption proposed in the article of the method is the use of the population containing classifiers and the population containing substitute network configuration solution variants for the considered distribution network malfunction state.

The first of the populations named constitutes a collection of classifiers (which serve as centres gathering information useful in the future for the formulation of post-malfunction substitute network configurations), which may be supplemented by newly obtained classifiers (which contain substitute network configuration scenarios for probable network malfunction states) that are recorded in the collection of classifiers with the use of the so-called press model (known in the theory of genetic algorithms) in order to maintain the constant number of the classifiers collection.

The second population is composed of five subpopulations of which each is connected with another optimisation criterion. During the implementation of the calculation process with the use of the co-evolutionary algorithm directing the exchange of information takes place (according to the procedures of the co-evolutionary algorithm described in point 2 between subpopulations in order to seek the collection of Pareto-optimal solutions.

In the first stage of the calculations performed with the proposed method are the announcement creation processes and the evaluation of classifiers (performed according to the genetic principles of self-teaching systems), consisting of the search in the collection of classifiers for information assisting the process of designating the solution to the analysed task.

During this part of the calculation classifiers are sought, the conditions of which are compatible with the announcement describing the existing state of electric power distribution network malfunction. For the consideration of the designated network malfunction state (during the announcement creation process) in the first stage of the classifiers registered in Table 1.

The classifiers, which fulfil this condition are described in the literature as active classifiers, values of the so-called offer are calculated for them (according to the procedures of the evaluation algorithm which is described in point 2. The evaluation takes place on the basis of the suitability of the information contained in particular classifiers. In the column relating to network configurations noted in the inversion vector only the initial and final elements of this vector are noted. In the last column of table number 1 contains the calculation results of the offer for particular classifiers.

According to the idea of classifying systems through the process of announcement creation, then follows the evaluation of the revealed classifiers, which consists of the calculation of the so-called offer of the classifiers being the measure of their suitability to resolve the analysed task. The offer for classifier number 1 (Table 1) calculated

Table 1. Active classifiers after first process evaluating

No	condition: (numbers of non-supplied nodes) and (numbers of fault elements)	answer of system (recorded in the vectors of inversion)	S_i	Bid	Current value S_i stren of the *i-th* classifie
1.	(8,22,28,29,31,73,178,195,291,292,338,339,23,167,32,72,179,196,287,293,337,340,24,168,33,71,180,197,288,294,336,341,25,34,70,181,198,289,295,335,330,26,69,182,199,290,296,334,329,331,68,177,194,286,297,333,328,176,193,285,332,192,284,191,187,188) and (line 6_8)	x,x,x,x,x,x,x,4,6,5,1,13,14,… ,7,7,554,7	$S_1 = 10$	$B_1 = 0{,}813$ $EB_1 = 0{,}802$	$S_1 = 10+$ $0{,}622$
2.	**(9,16,20,21,57,80,81,101,117,120,138,201,208,376,409,15,19,27,56,79,544,100,116,121,136,202,207,377,408,14,18,55,78,545,99,115,122,135,137,206,378,406,13,17,54,77,546,98,114,205,379,407,12,283,53,76,547,97,204,380,358,52,549,550,203,368,359,51,548,551,360,50,552,361,362,363) and (line 6_9)**	**x,x,x,x,x,x,x,6,2,5,7,13,14,… ,7,7,554,7**	$\mathbf{S_2 = 10}$	$\mathbf{B_2 = 0{,}823}$ $\mathbf{EB_2 = 0{,}831}$	$\mathbf{S_2 = 10+2}$
3.	*(178, 179, 180, 181, 182, 177, 178) and (8_22)*	x,x,x,x,x,x,x,6,2,5,7,13, , … ,7,554,7	$S_3 = 10$	$B_3 = 0{,}423$ $EB_3 = 0{,}501$	$S_3 = 10+$ $0{,}211$

according to dependencies 2 and 3 amounted appropriately to $B_1 = 0,813$ and $EB_1 = 0,802$. Whereas the offer for classifier number 2 amounted correspondingly to $B_2 = 0,823$ and $E_2 = 0,831$ and the offer for classifier number 3: $B_3 = 0,423$ and $E_3 = 0,501$.

The solution sought is the electric power distribution network substitute configuration, enabling the restoration of power supplies to consumer network nodes. Information obtained in the processes of creating announcements and the evaluation of classifiers is used in the proposed method to create initial populations subsequently used by the co-evolutionary algorithm. This algorithm is based simultaneously on 5 subpopulations, from which each evaluation was the basis for another adaptation function (dependencies 4 to 8). The sought-after solution in this case is a collection of solutions in the form of alternative configurations of the analysed network. The choice of the final solution variant depends upon the decision maker decider, who in this instance may be the operator managing the operation of the electric power Medium Voltage distribution network.

On the graphs in Figs. 5(a) and 6(a) the course of the change of values of best solutions is shown in chosen subpopulations 3 and 4 in the event that an evolutionary algorithm began calculation with randomly generated initial subpopulations.

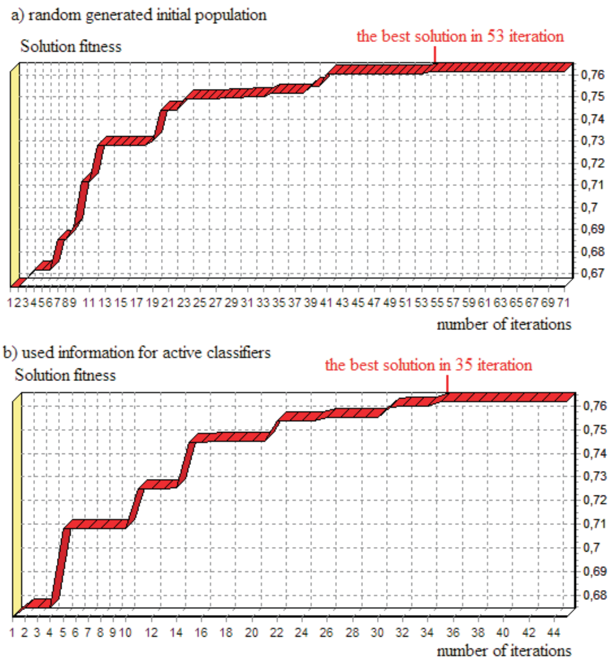

Fig. 5. Example of best solutions fitness in subpopulation number 3: (a) random generated initial population; (b) used information for active classifiers

For comparison the course of such calculations in the event of using information obtained from the collection of classifiers and the subpopulations formulation stage is presented. Cooperation of the co-evolutionary algorithm with the classification system enables significant reduction of time of obtainment of solutions (reduces the iterative calculation process on average by 40 %), which is significant from the practical point of view in the application of this method in current systems of distribution network operation management.

The proposed calculation model includes criteria which the author has defined as maximization or minimization of values referring to individual optimization criteria. The criteria concerning maximization have been converted for the purposes of the minimization task. Such operation has facilitated finding the weakest (in terms of criteria 2, 3 and 5) power transmission lines in a given grid configuration.

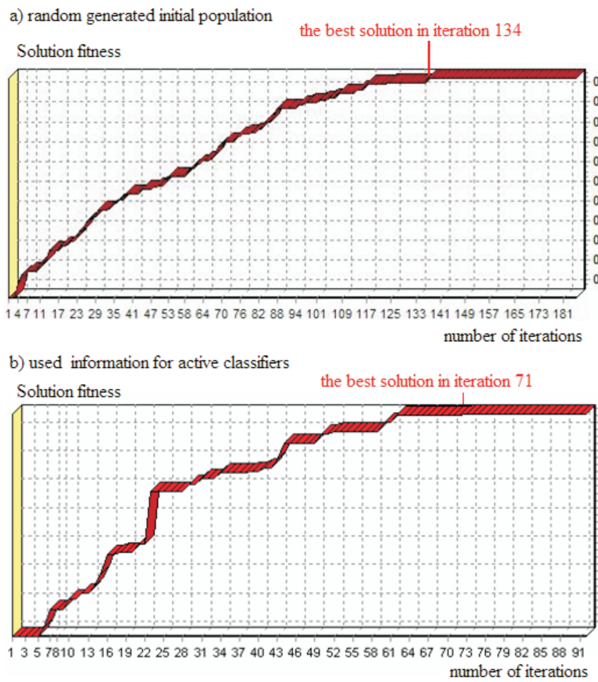

Fig. 6. Example of best solutions fitness waveform in subpopulation number 4: (a) random generated initial population; (b) used information for active classifiers

The main aim of adopting such a method for describing optimization criteria was to find the solutions with the most favorable grid configuration efficiency ratios and at the same time minimize the ratios referring to the weak points of the analyzed solutions. The author has subsequently applied the membership function as described by formula (9) in order to express all the criteria as a maximization task.

Following the procedure carried out by means of the proposed evolutionary algorithm, the values referring to the most favorable grid configurations found can be calculated by means of formulae 4-8, which include, among others, the number of switching operations (leading to a new grid configuration) or maximum grid voltage deviation. Sample results of the calculations in the form of

Table 3. Results for subpopulations

Criterion no.	Results for subpopulation number 1	Results for subpopulation number 2	Results for subpopulation number 3	Results for subpopulation number 4	Results for subpopulati number 5
1	$\mathbf{L_{pz} = 4}$ $\mathbf{u_1(X)=0,893}$	$L_{pz} = 11$ $u_1(X)=0,671$	$L_{pz} = 10$ $u_1(X) =0,707$	$L_{pz} = 13$ $u_1(x) =0,621$	$L_{pz} = 14$ $u_1(x) =0,619$
2	$p=0,998031$ $u_2(x)=0,896$	$\mathbf{p = 0,998381}$ $\mathbf{u_2(x) = 0,998}$	$p = 0,998152$ $u_2(x) = 0,943$	$p = 0,997752$ $u_2(x) = 0,790$	$p = 0,998261$ $u_2(x) = 0,985$
3	$\delta U = 2,23$ % $u_3(x =0,647$	$\delta U = 1,22$ % $u_3(x) = 0,752$	$\mathbf{\delta U = 1,18}$ **%** $\mathbf{u_3(x) = 0,765}$	$\delta U = 1,31$ % $u_3(x) = 0,734$	$\delta U = 1,22$ % $u_3(x) = 0,752$
4	$\Delta P =2895$ kW $u_4(x) =0,635$	$\Delta P =2679$ kW $u_4(x) =0,667$	$\Delta P =2675$ kW $u_4(x) =0,670$	$\mathbf{\Delta P=2561}$ **kW** $\mathbf{u_4(x) =0,740}$	$\Delta P = 2654$ kW $u_4(x) =0,682$
5	$k_{obc} = 0,669$ $u_5(x) = 0,743$	$k_{obc} = 0,584$ $u_5(x) = 0,886$	$k_{obc} = 0,577$ $u_5(x) =0,898$	$k_{obc} = 0,771$ $u_5(x) =0,669$	$\mathbf{k_{obc} = 0,544}$ $\mathbf{u_5(x) =0,955}$

a list of the most favorable solutions in five subpopulations are presented in Table 3.

The results of calculations are presented in graphic form in Figs. 7 and 8. The figures present the chosen (appropriate to the best solution of subpopulation numbers 3) designated substitute configuration of the analysed network. In these figures these differences are marked (associated with connection activities scenarios) between primary configuration in Fig. 3 and designated substitute configuration of the analysed network.

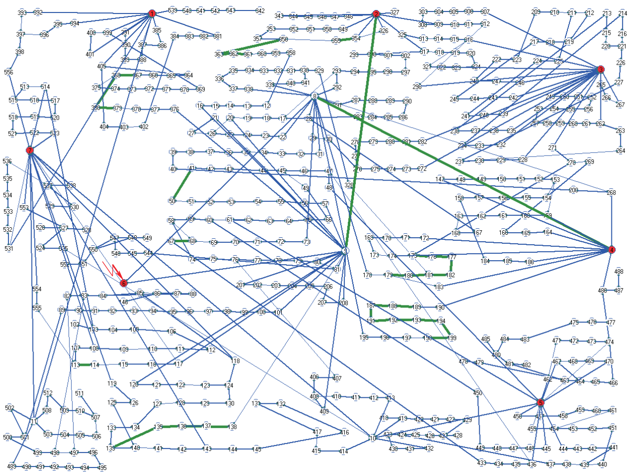

Fig. 7. Graph of the analysed distribution network with network configurations, being the best solution obtained in subpopulation 3

The final decision of selection of solution variant (among the sought after collection of solutions with particular subpopulations) may be taken by the operator managing work of the electric power distribution network. In cooperation of the coevolutionary algorithm with the classifying system after performance of the calculation process the best solutions obtained from particular subpopulations the solutions are written into the classifier collection.

5. Conclusion

During the implementation of the computer simulation of malfunction states and calculations designating substitute network configurations, the author observed that information used contained in the collection of classifiers (with current supplementation and updating capability) enables increasing the effectiveness of the solutions search process with the use of evolutionary algorithms. Cooperation of the co-evolutionary algorithm with the classifier system enables significant reduction of the time calculations (reduces the iterative calculation process on average by 40 %), which is significant from the practical point of view in the application of this method in current systems of distribution network operation management. 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 to create sub-populations of solutions for the co-evolutionary algorithm, which would be used to search for the collection of Pareto-optimal solutions. The process of creating a collection of classifiers describing the substitute network configuration was performed by the author supported by the theoretical genetic basics of self-teaching system.

Classifiers may be created for the most probable break down situations, which arise from regarding the stage of choice of the simulated break down situations reliability characteristics and the usage durations of network elements. The result of the works performed is the drawing up of an effective method enabling the rapid designation of substitute network configurations, also for very complex network structures. Results obtained within the research performed, in the form of drawn up procedures creating the most effective configuration of network appliances operation, may be used as an element of large, very complex information systems used in electric power distribution networks. According to the monitoring presented in the literature on the problem, the application of integrated information systems assisting network management achieves optimisation of the decision processes of the system operator and with the effect of achieving the required level of service, by the minimising outlay for the maintenance of the network and appliances in the condition guaranteeing supply of electric power of the required parameters in the quantities needed by the consumers.

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